

Ways of Viewing and Interpreting Ensemble Forecasts: Applications in Severe Weather Forecasting

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***NOAA/NWS/Storm Prediction Center
Norman, OK***

**AMS Short Course on
Ensemble Prediction: Conveying Forecast Uncertainty**

**14 January 2007
San Antonio, TX**



Where Americas Climate and Weather Services Begin



Outline

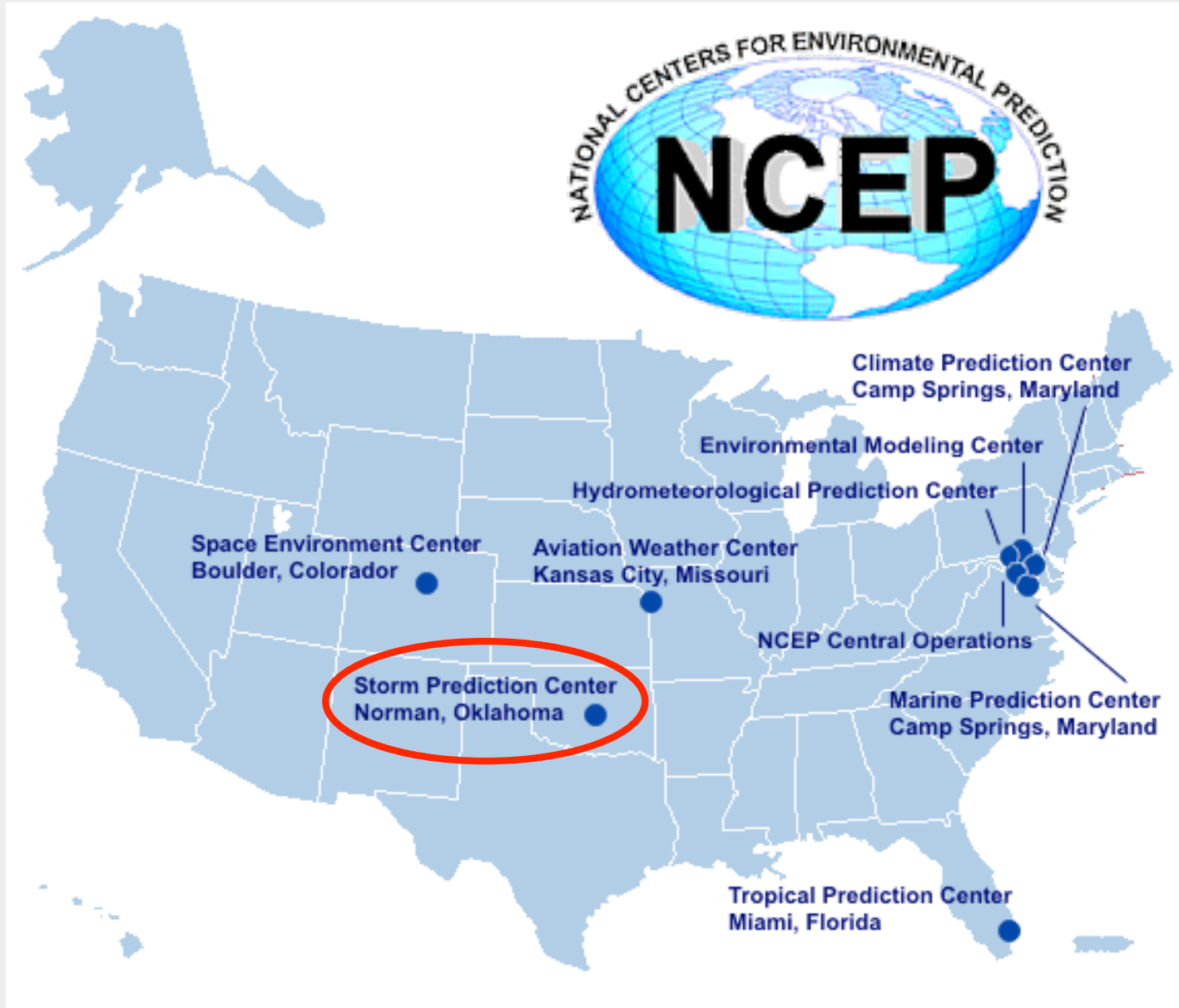
- Introduction
- Applications in Severe Weather Forecasting
 - Fire Weather
 - Winter Weather
 - Severe Convective Weather
- Summary



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- **Introduction**
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 - Fire Weather
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STORM PREDICTION CENTER

MISSION STATEMENT

The Storm Prediction Center (SPC) exists solely to protect life and property of the American people through the issuance of timely, accurate watch and forecast products dealing with hazardous mesoscale weather phenomena.





STORM PREDICTION CENTER



HAZARDOUS PHENOMENA

- Hail, Wind, Tornadoes
- Excessive rainfall
- Fire weather
- Winter weather



Severe Weather Forecasting

- **The Challenge**: High impact events often occur on temporal and spatial scales below the resolvable resolutions of most **observing and forecasting** systems
- **Key premise**: We must use knowledge of the environment and non-resolved processes to determine the spectrum of severe weather possible, where and when it may occur, and how it may evolve over time

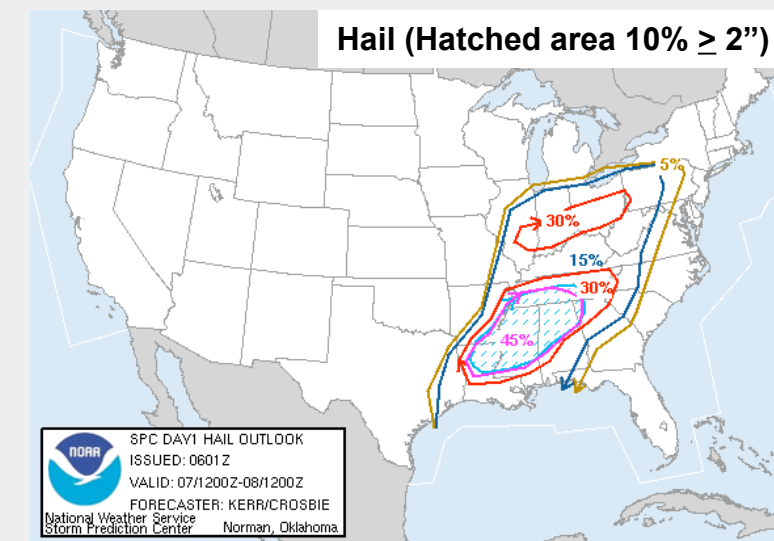
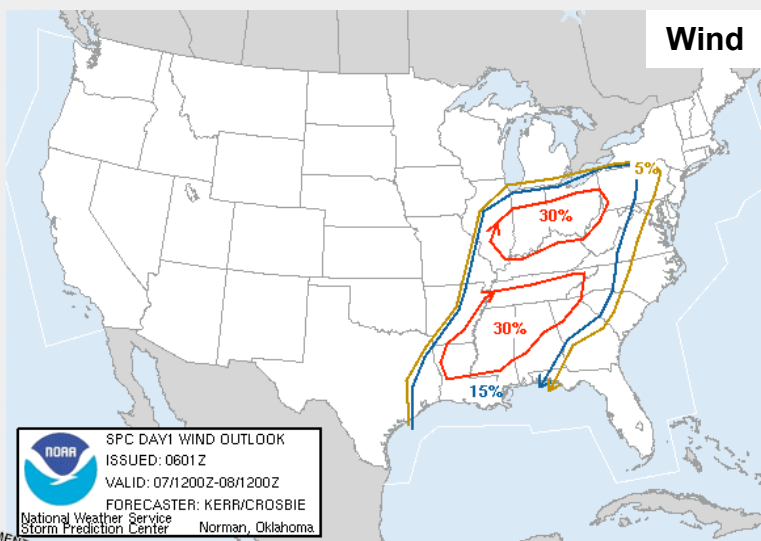
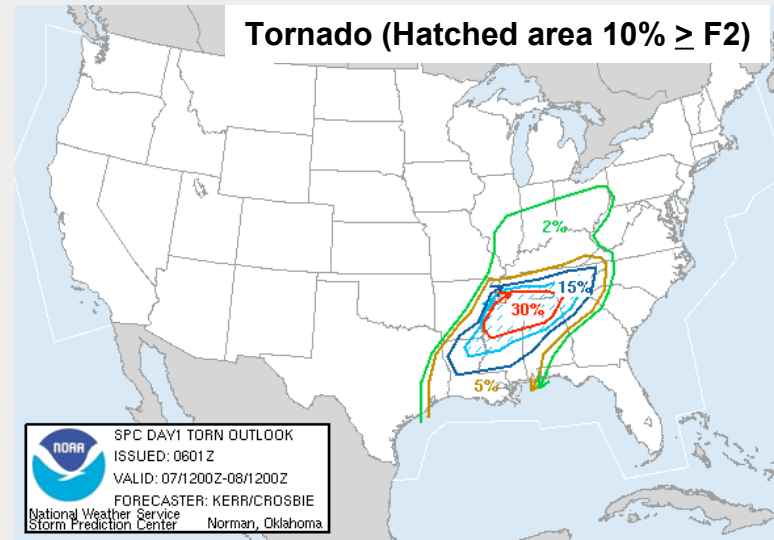
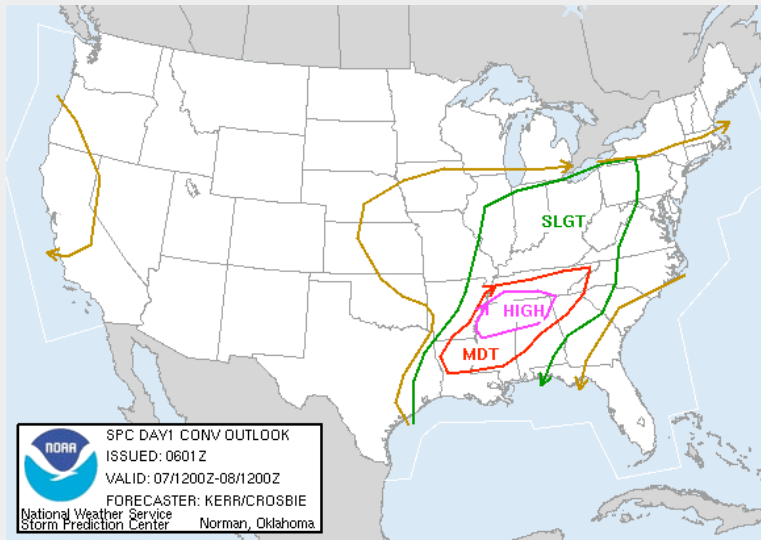


Severe Weather Forecasting

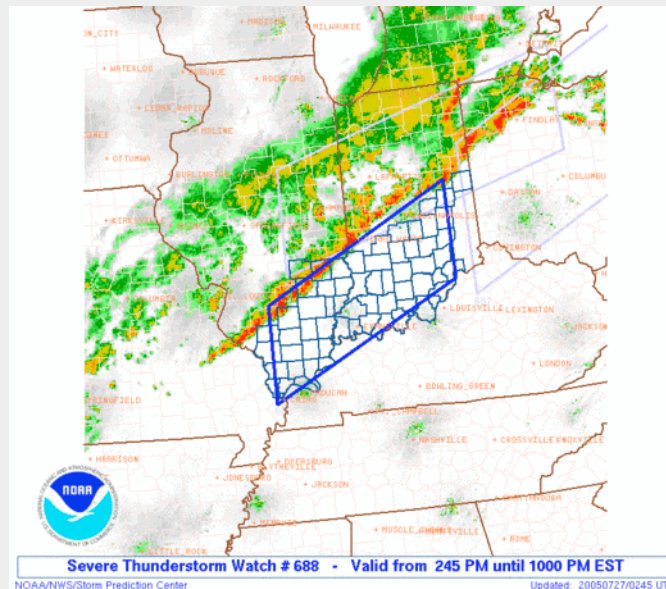
- **Observational data and diagnostic tools**
 - Key input for short-term prediction, i.e., “Nowcast”
 - But high-impact weather events typically occur on scales smaller than standard observational data
 - Environment not sampled sufficiently to resolve key fields (especially 4D distribution of water vapor)
- **Model forecasts**
 - Supplement observational data in short term
 - Increasing importance beyond 6-12 hr
 - Typically do not resolve severe phenomena
 - Deterministic model errors are related to analysis and physics errors
- **Uncertainty addressed through probabilistic-type products**

CONVECTIVE OUTLOOKS

Categorical and Probabilistic: Operational through Day 3; Exp through Day 8



OPERATIONAL WATCH PROBABILITIES

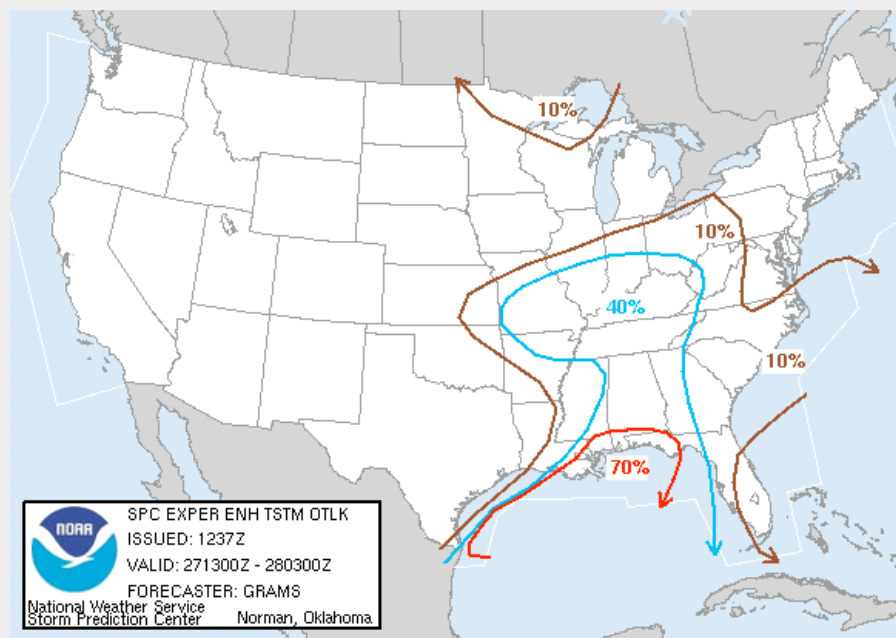


Severe Thunderstorm Watch 688 Probability Table

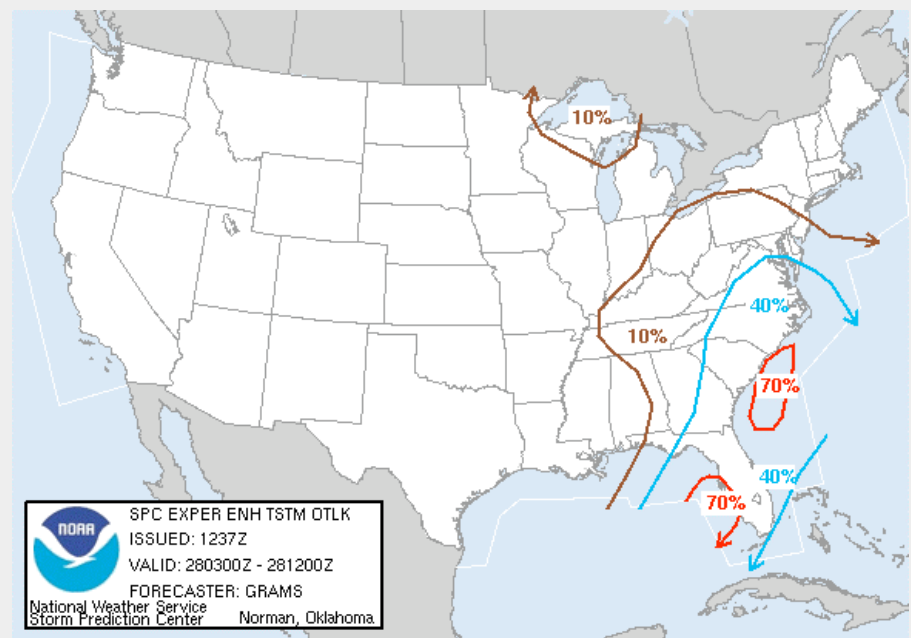
Tornadoes	
Probability of 2 or more tornadoes	Low (10%)
Probability of 1 or more strong (F2-F4) tornadoes	Low (<5%)
Wind	
Probability of 10 or more severe wind events	Mod (60%)
Probability of 1 or more wind event > 65 knots	Low (10%)
Hail	
Probability of 10 or more severe hail events	Low (10%)
Probability of 1 or more hailstones >2 inches	Low (<5%)
Combined Severe Hail/Wind	
Probability of 6 or more combined severe wind/hail events	Mod (60%)

Experimental Enhanced Thunderstorms Outlooks

Thunderstorm Graphic valid until 3Z



Thunderstorm Graphic valid 3Z to 12Z



Guidance Addressing Uncertainty

- Deterministic models reveal one end state, while ensembles
 - *Provide a range of plausible forecast solutions, yielding information on forecast confidence and uncertainty (probabilities)*
- Ensemble systems supplement traditional (higher resolution) deterministic models
- Ensemble systems aid in decision support
 - *Particularly if guidance calibrated (i.e., correct for systematic model bias and deficiencies in spread)*

Ensemble Guidance at the SPC

- **Develop specialized guidance for the specific application (severe weather, fire weather, winter weather)**
- **Design guidance that...**
 - Helps blend deterministic and ensemble approaches
 - Facilitates transition toward probabilistic forecasts
 - Incorporates larger-scale environmental information to yield downscaled probabilistic guidance
 - Aids in decision support of high impact weather
 - Gauge confidence
 - Alert for potentially significant events



Commonly Used Ensemble Guidance at the SPC

- Mean, Median, Max, Min, Spread, Exceedance Probabilities, and Combined Probabilities
 - Basic Weather Parameters
 - *Temperature, Height, MSLP, Wind, Moisture, etc.*
 - Derived Severe Weather Parameters
 - *CAPE, Shear, Supercell and Sig. Tornado Parameters, etc.*
 - Calibrated Probability of Thunderstorms and Severe Thunderstorms

NCEP/EMC

Short Range Ensemble Forecast (SREF)

- EMC SREF system (21 members)
 - *87 hr forecasts four times daily (03, 09, 15, 21 UTC)*
 - *North American domain*
 - *Model grid lengths 32-45 km*
 - *Multi-model: Eta, RSM, WRF-NMM, WRF-ARW*
 - *Multi-analysis: NAM, GFS initial and boundary conds.*
 - *IC perturbations and physics diversity*

NCEP/EMC

Medium Range Ensemble Forecast (MREF)

<u>Model</u>	<u>Res</u>	<u>Levels</u>	<u>Mems</u>	<u>Cld Physics</u>	<u>Convection</u>
GFS	T126* (~ 105 km)	28	14**	GFS physics	Simple A-S

* Same as the operational GFS in 1998

** 14 statistically independent perturbations (using Ensemble Kalman filter method)



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Fire Weather Ingredients:

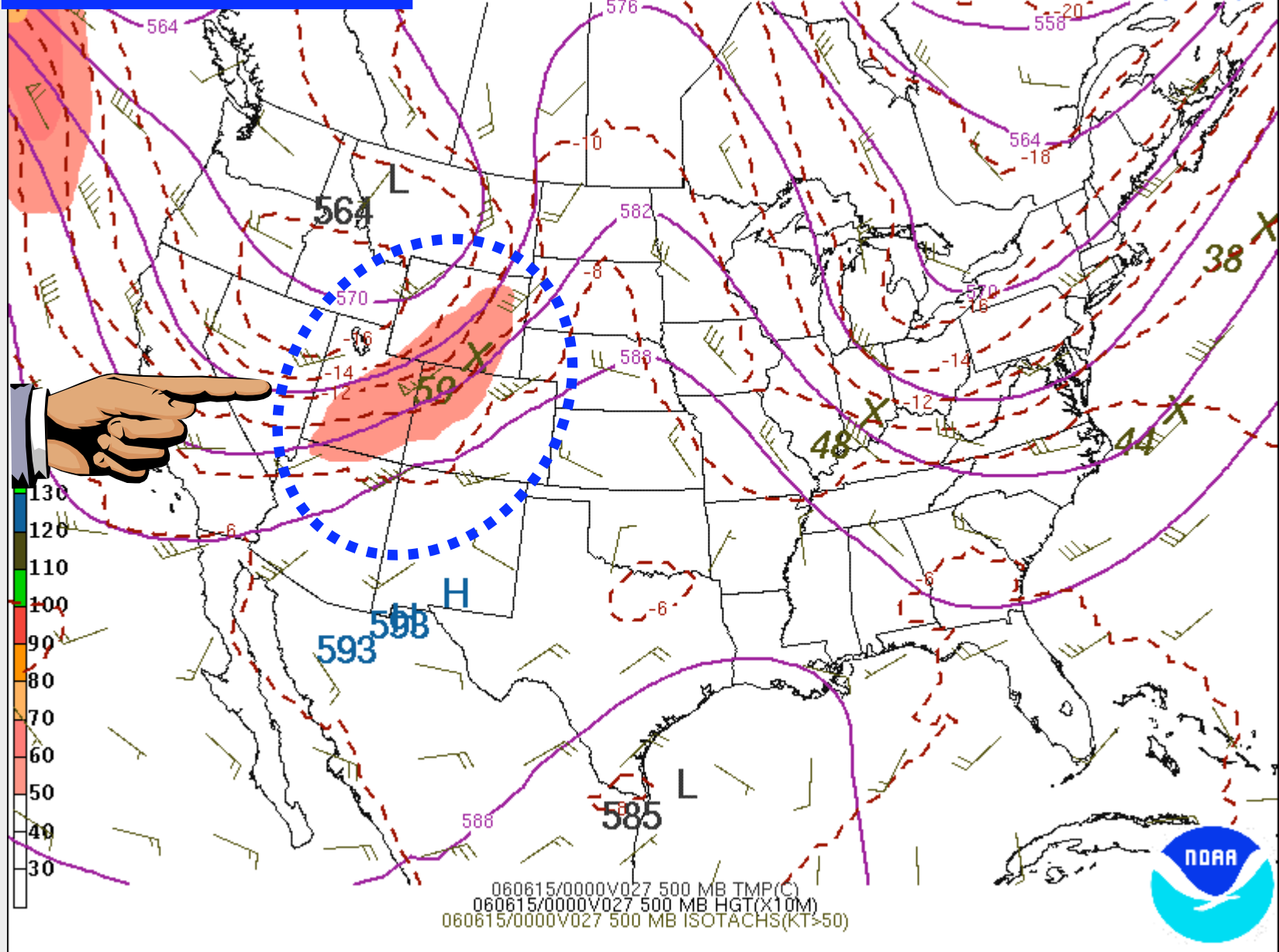
- 1) Dry low-level airmass (i.e., low RH)
- 2) Windy
- 3) No precipitation
- 4) Warm temperatures
- 4) Dry Thunderstorms (i.e., natural ignition source)



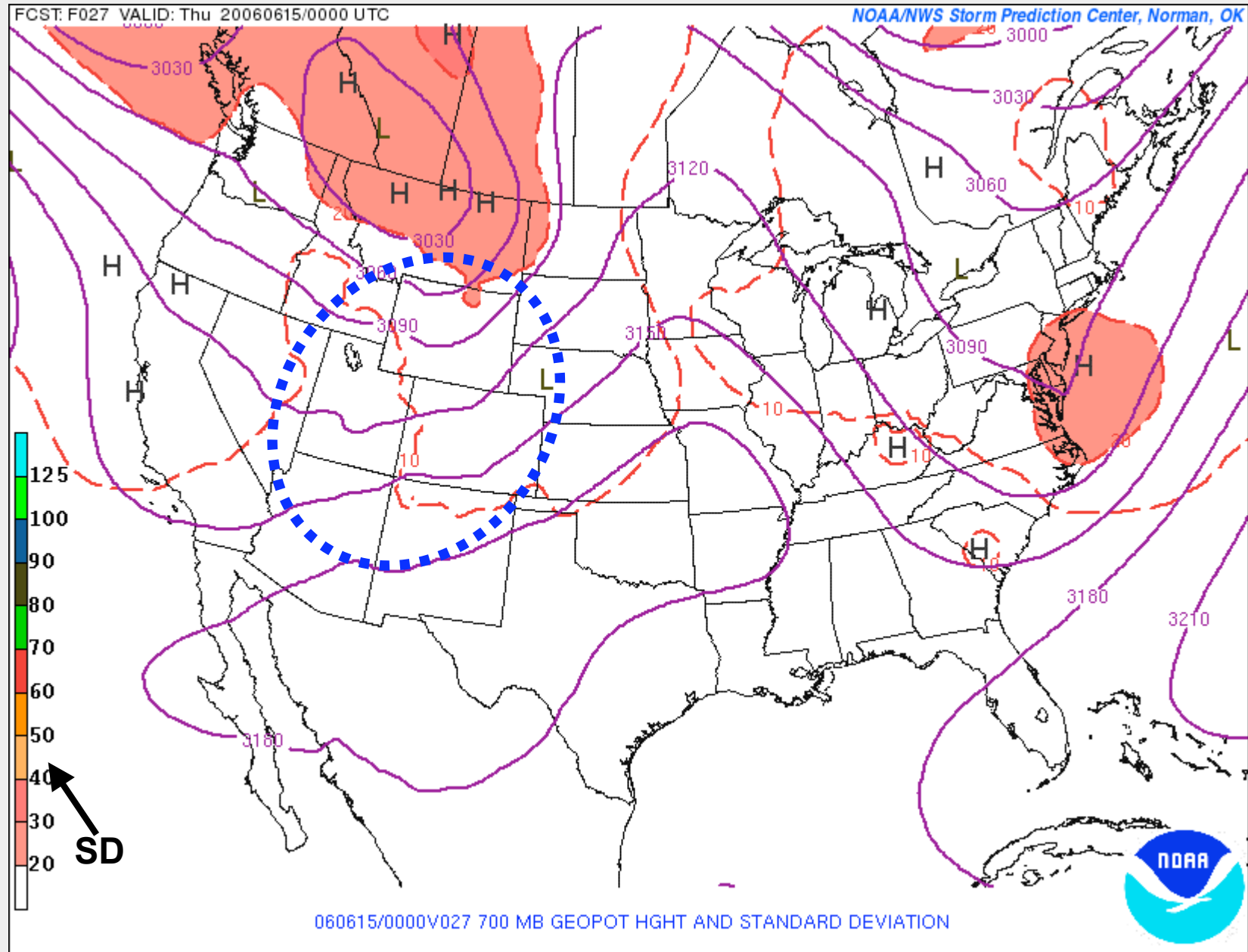
SREF 500 mb Mean Height, Wind, Temp

FCST: F027 VALID: Thu 20060615/0000 UTC

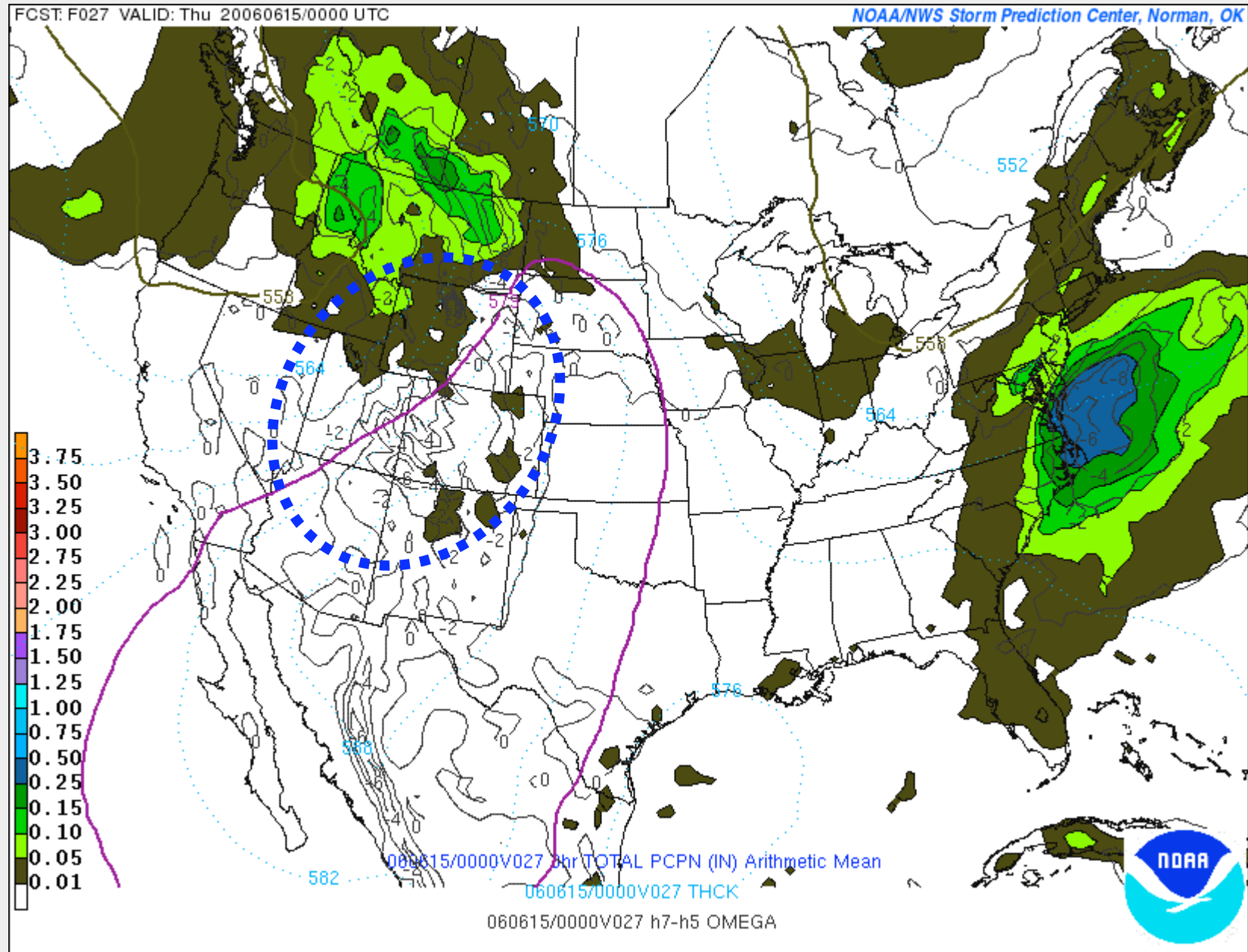
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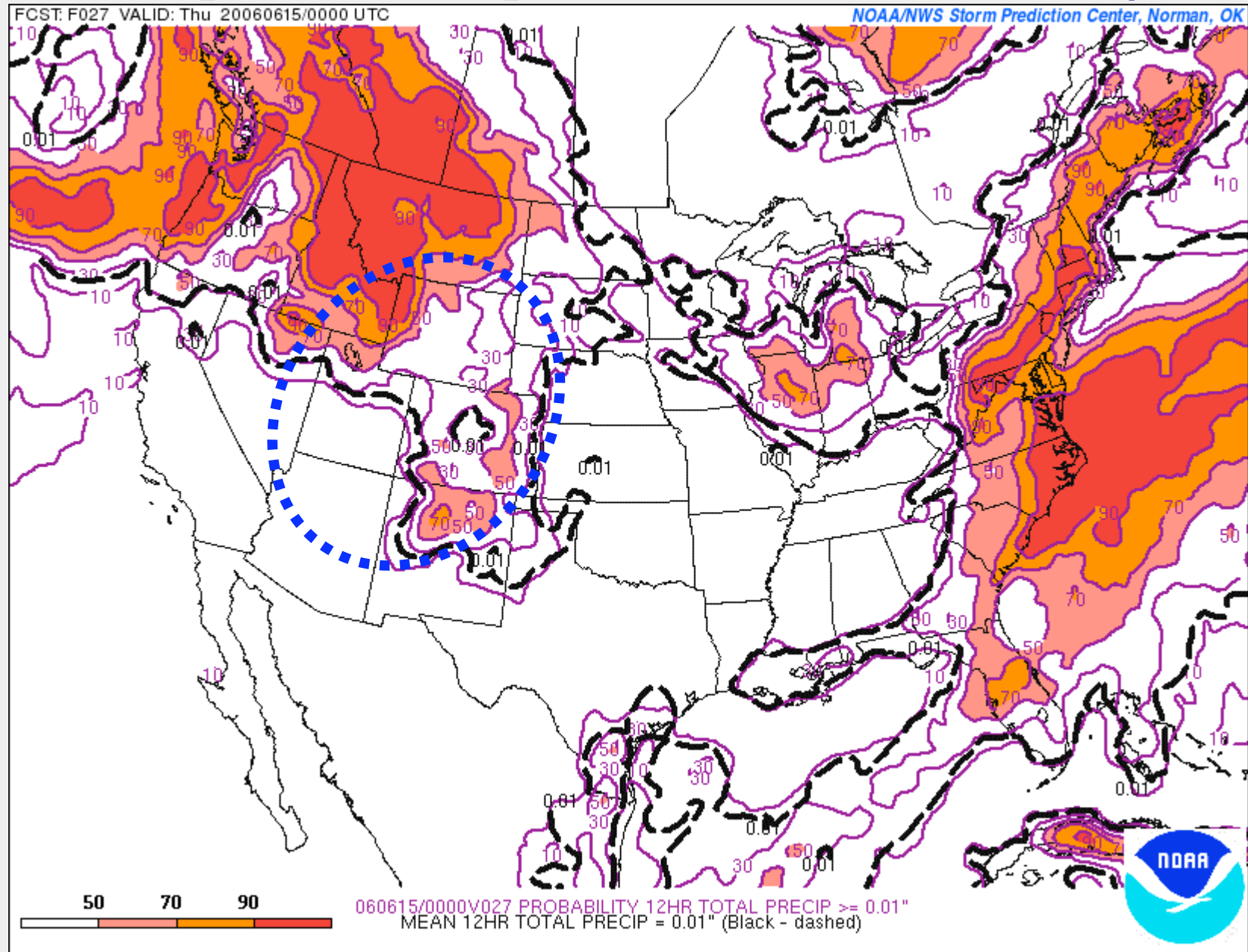
SREF 500 mb Mean Height and SD (dash)



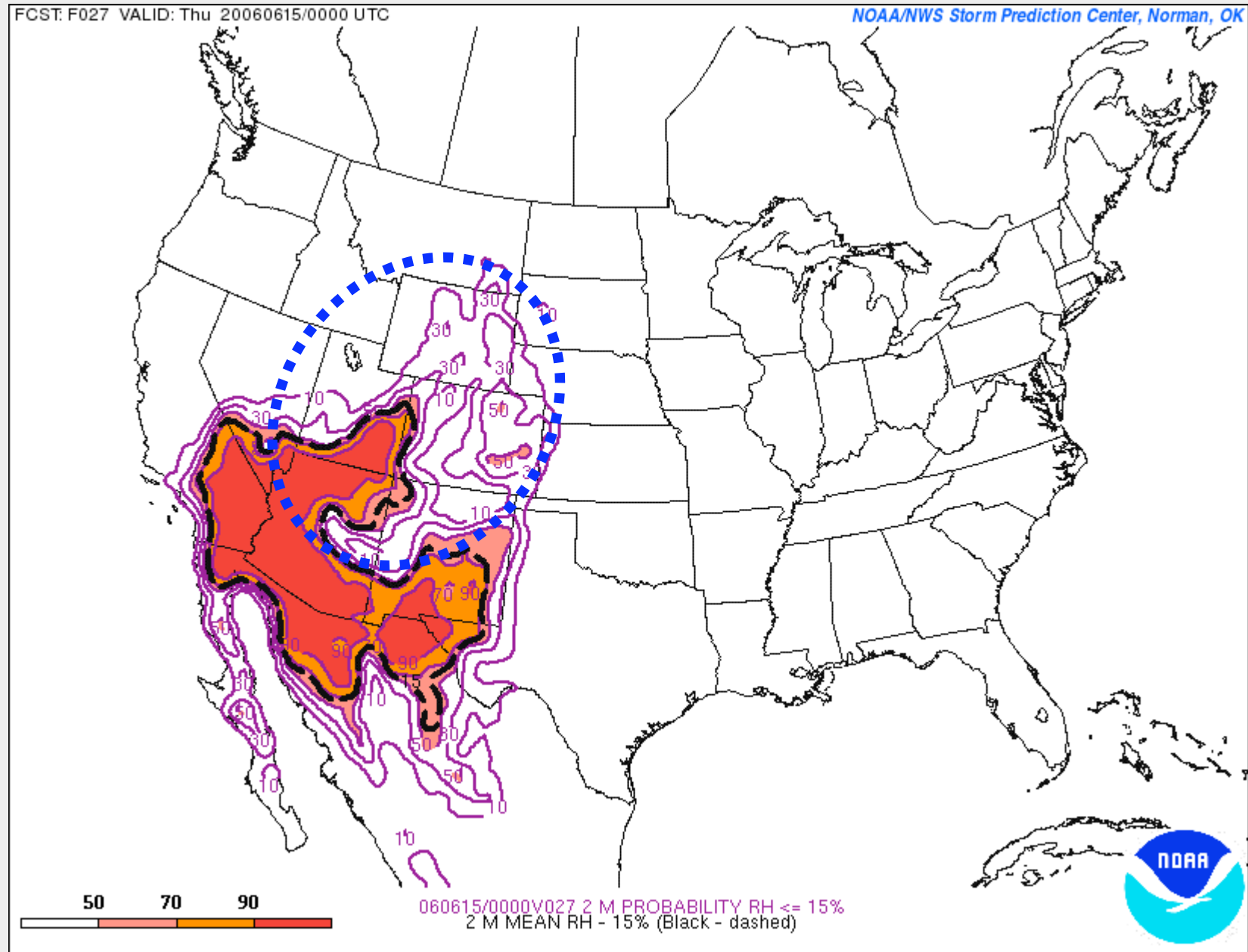
SREF Mean PCPN, UVV, Thickness



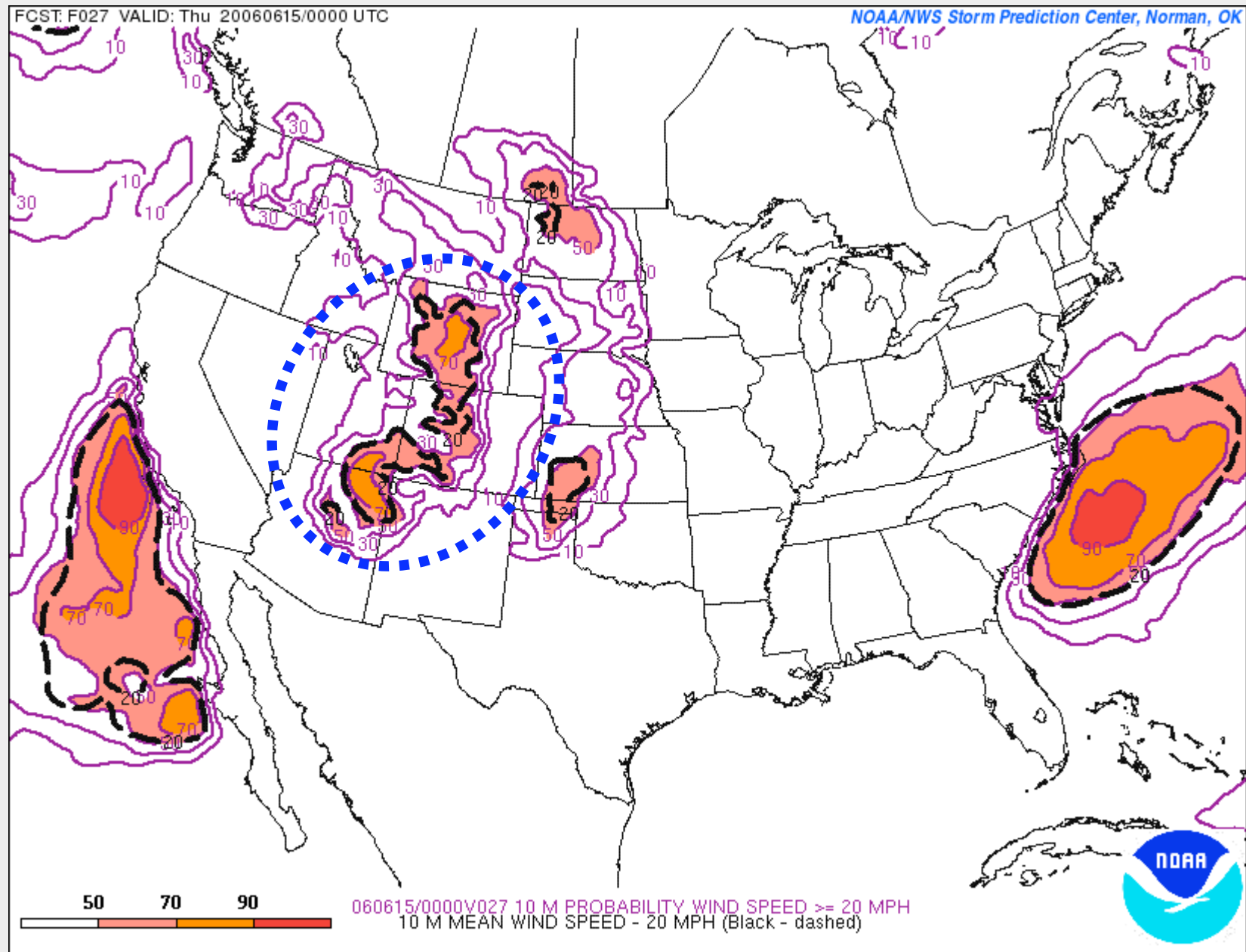
SREF Pr[P12I \geq .01"] and Mean P12I = .01" (dash)



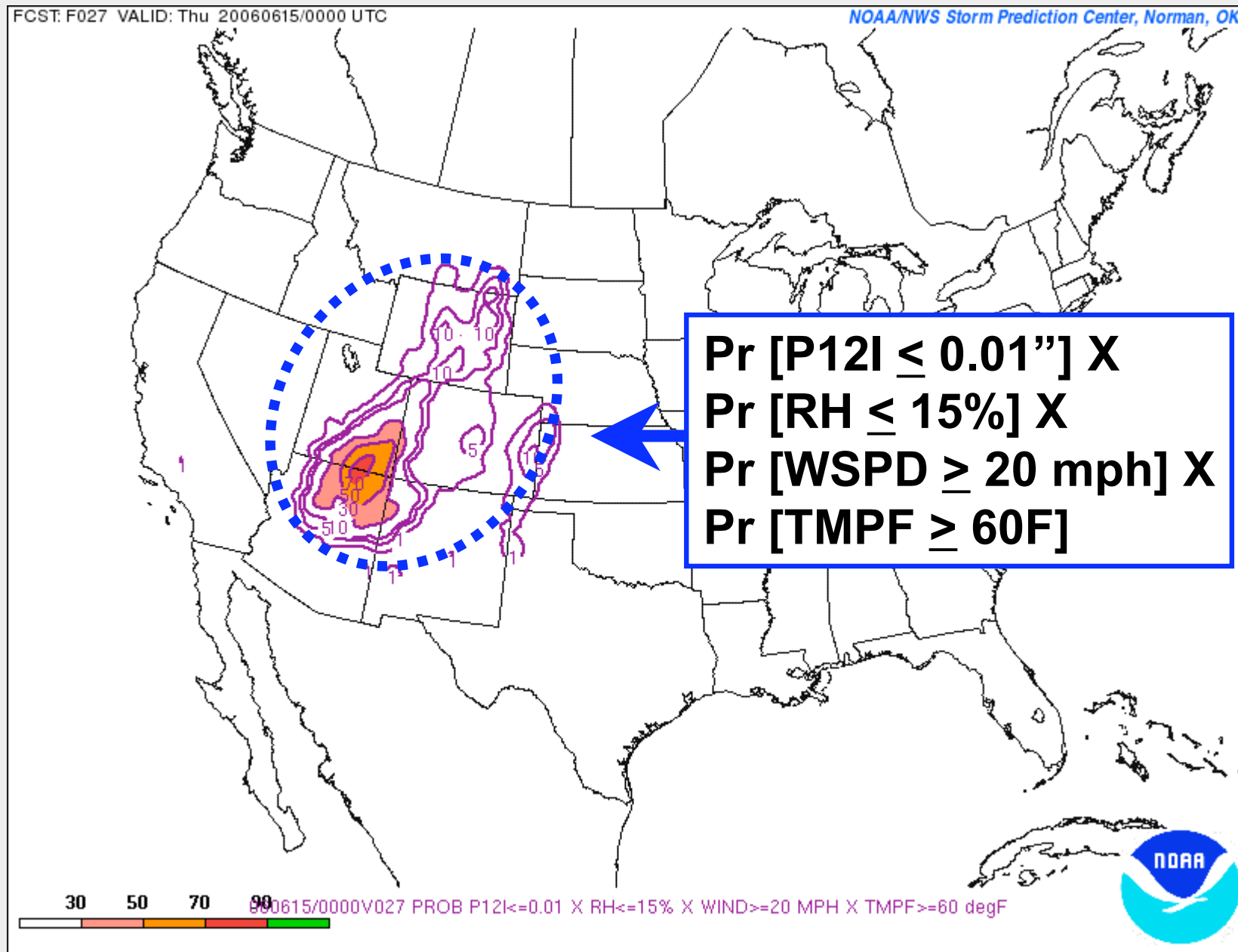
SREF Pr[RH \leq 15%] and Mean RH = 15% (dash)



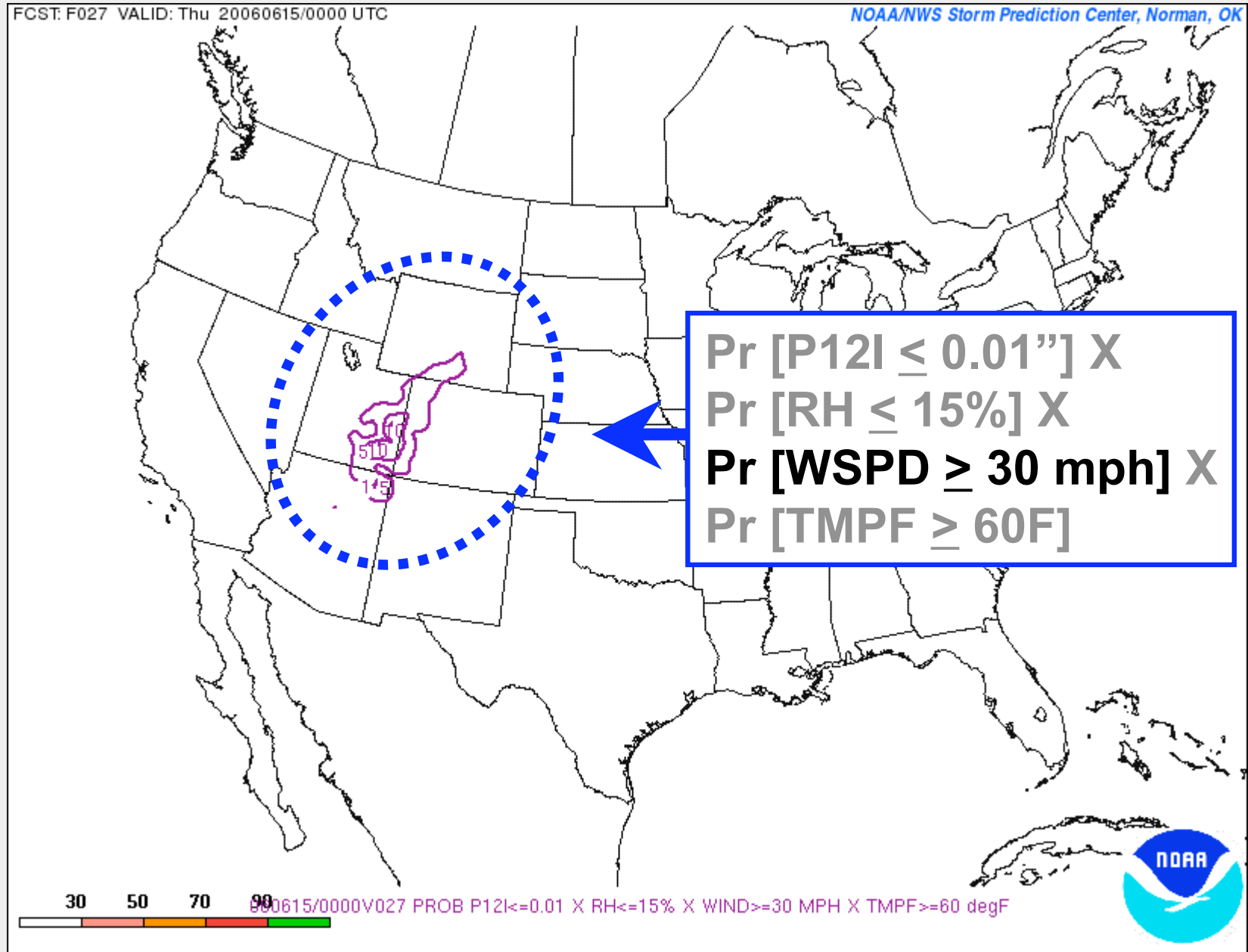
SREF Pr[WSPD \geq 20 mph] and Mean WSPD = 20 mph (dash)



SREF Combined or Joint Probability



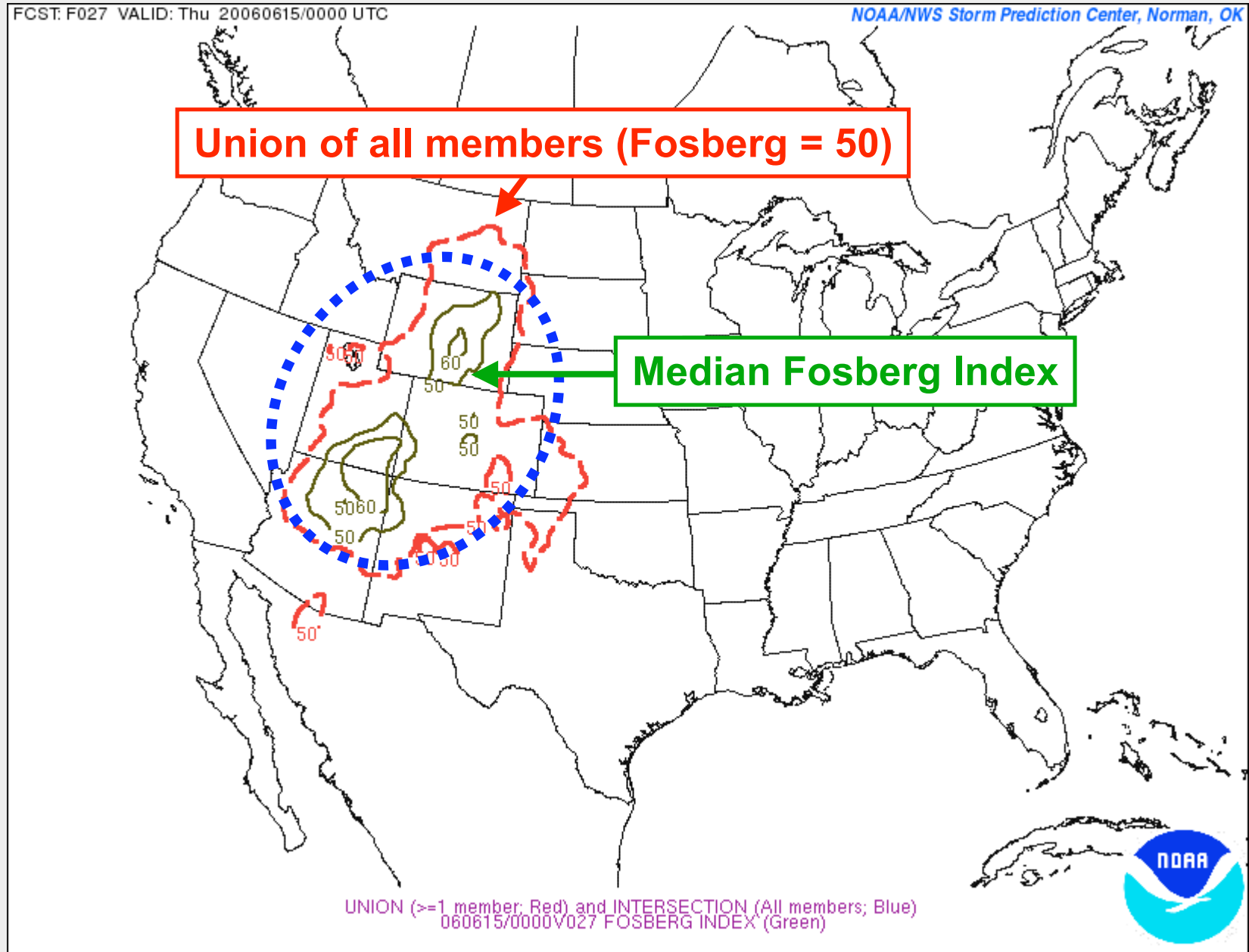
SREF Combined or Joint Probability



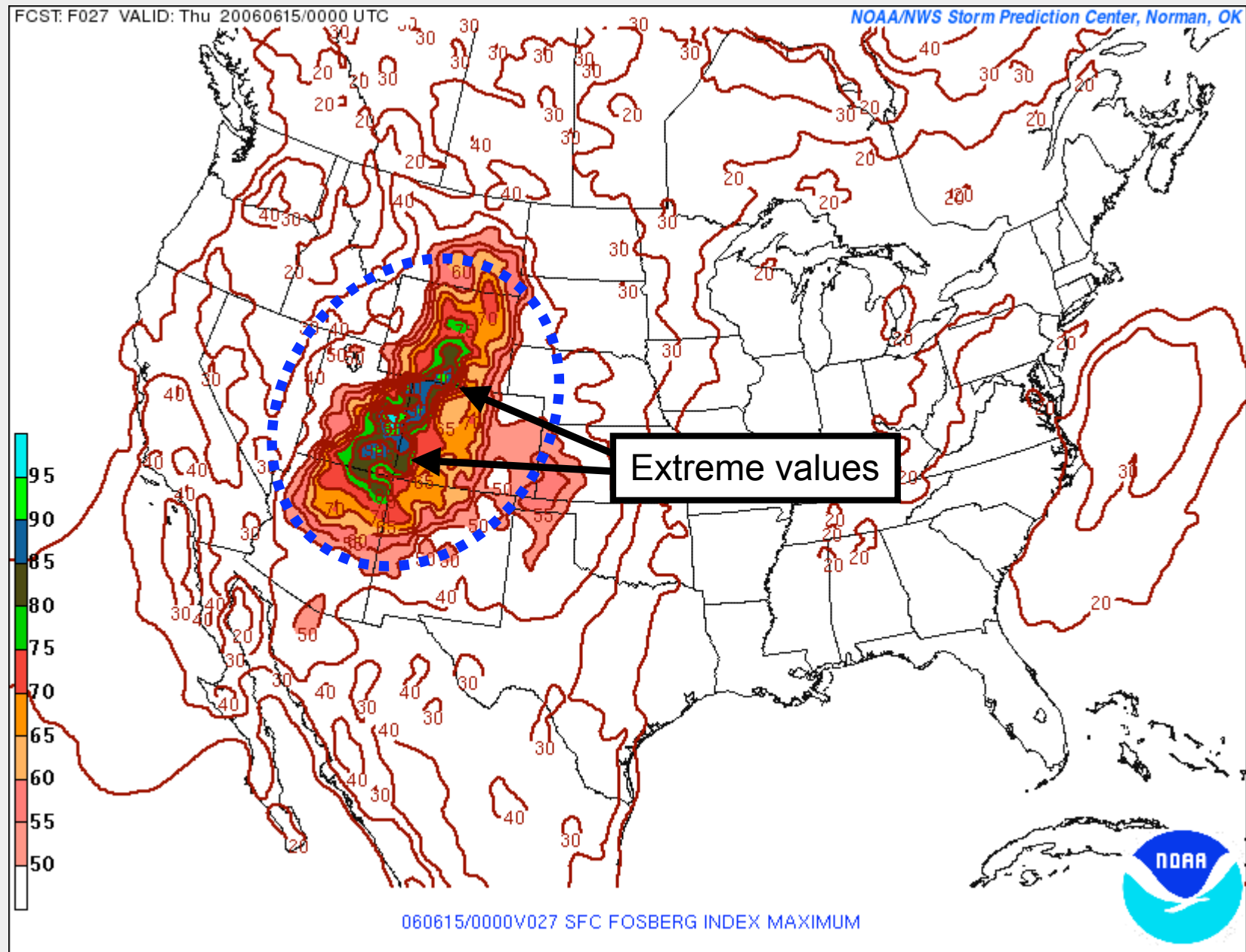
Diagnostics and Analysis

- Example: *Fosberg Fire Weather Index (FFWI)*
 - A nonlinear empirical relationship between meteorological conditions and fire behavior. (Fuels are not considered!)
 - Derived to highlight the fire weather threat over “small” space and time scales
- $FFWI = \mathcal{F}(\text{Wind speed, RH, Temperature})$
 - $0 \leq FFWI \leq 100$
 - $FFWI > \sim 50-60 \rightarrow \text{significant fire weather conditions}$
 - $FFWI > \sim 75 \rightarrow \text{extreme fire weather conditions}$

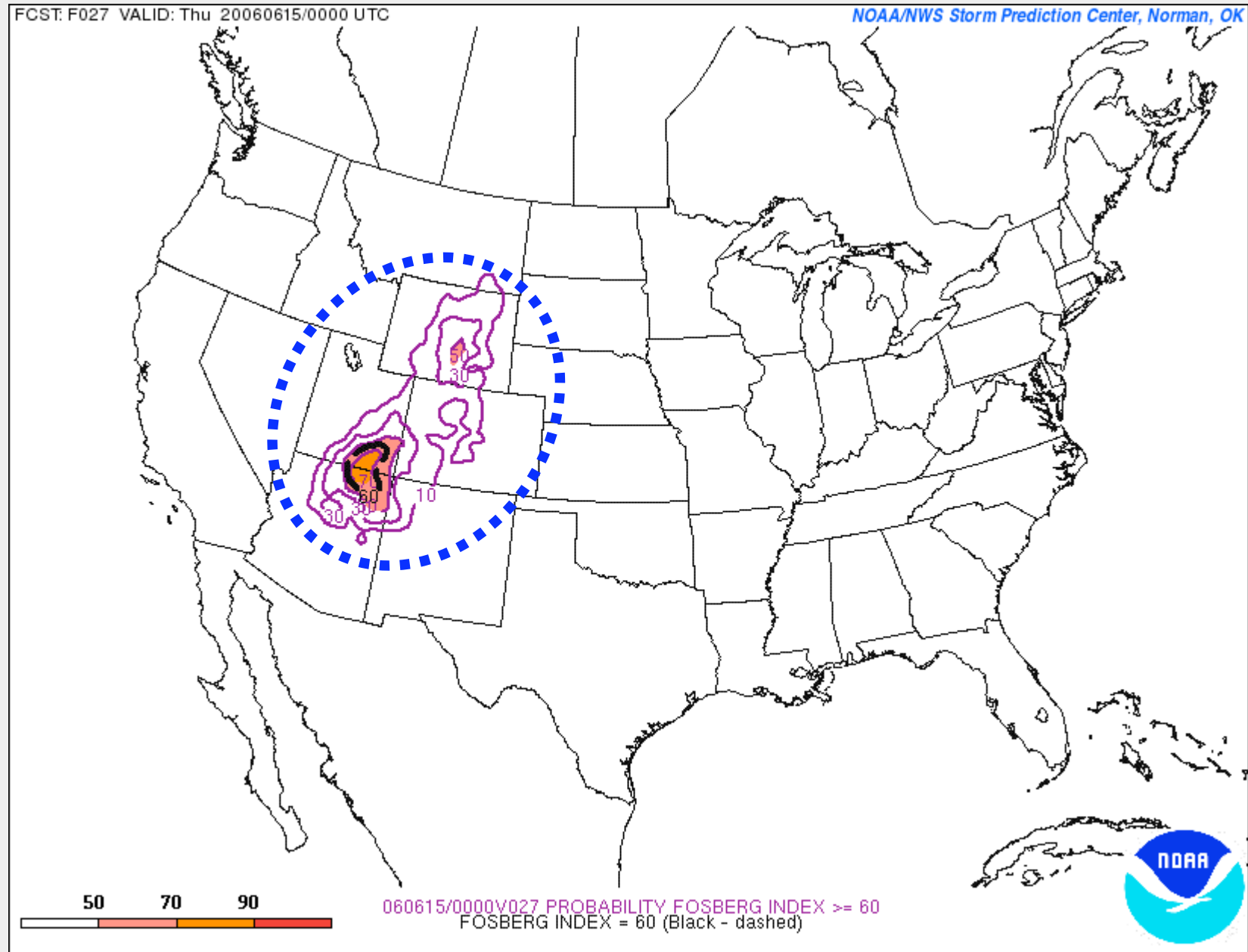
SREF Median Fosberg Index + Union (red)



SREF Maximum Fosberg Index (any member)



SREF Pr[Fosberg Index ≥ 60] and Mean FFWI = 60



SREF 3h Calibrated Probability of Thunderstorms

FCST: F027 VALID: Thu 20060615/0000 UTC

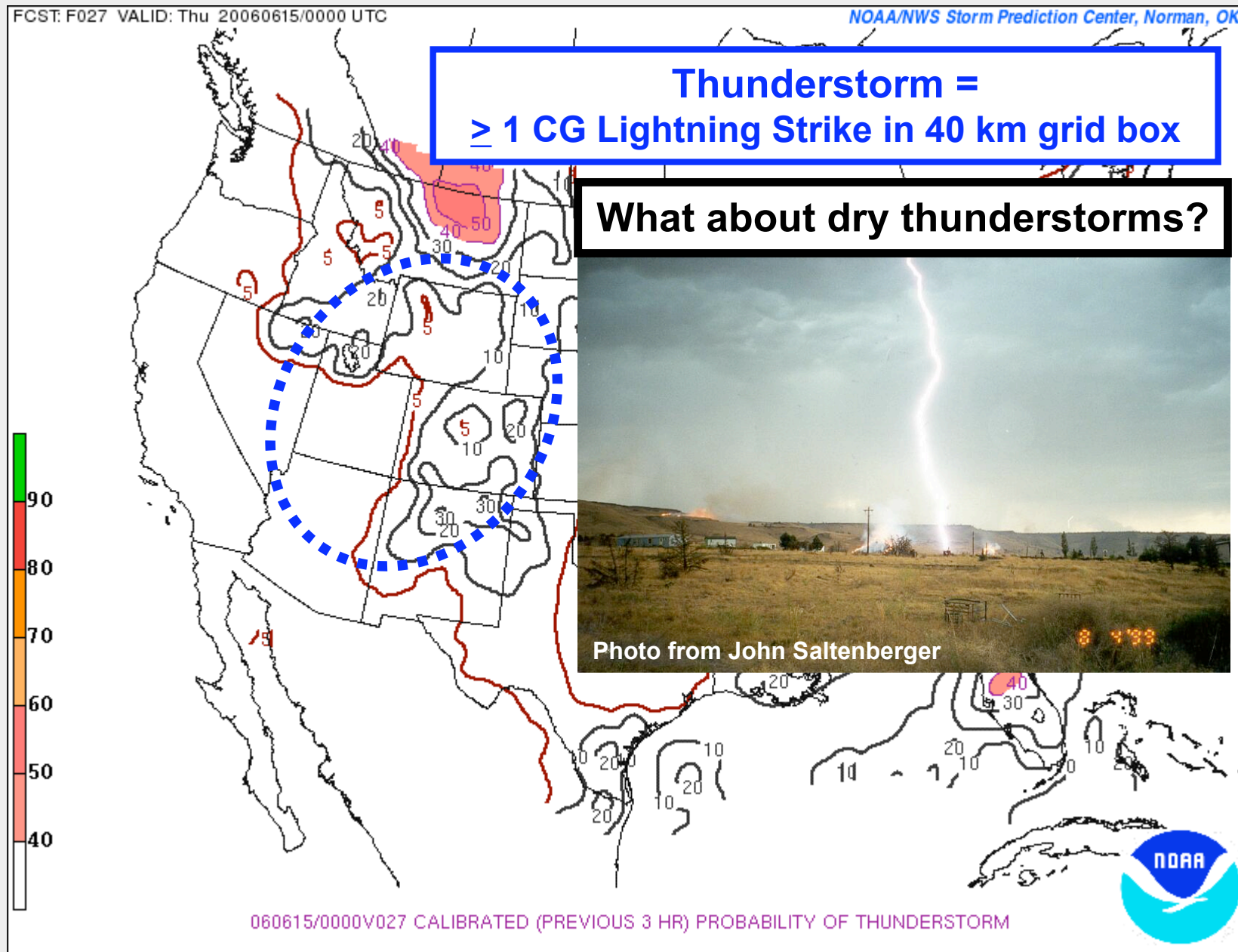
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**Thunderstorm =
 ≥ 1 CG Lightning Strike in 40 km grid box**

What about dry thunderstorms?



Photo from John Saltenberger

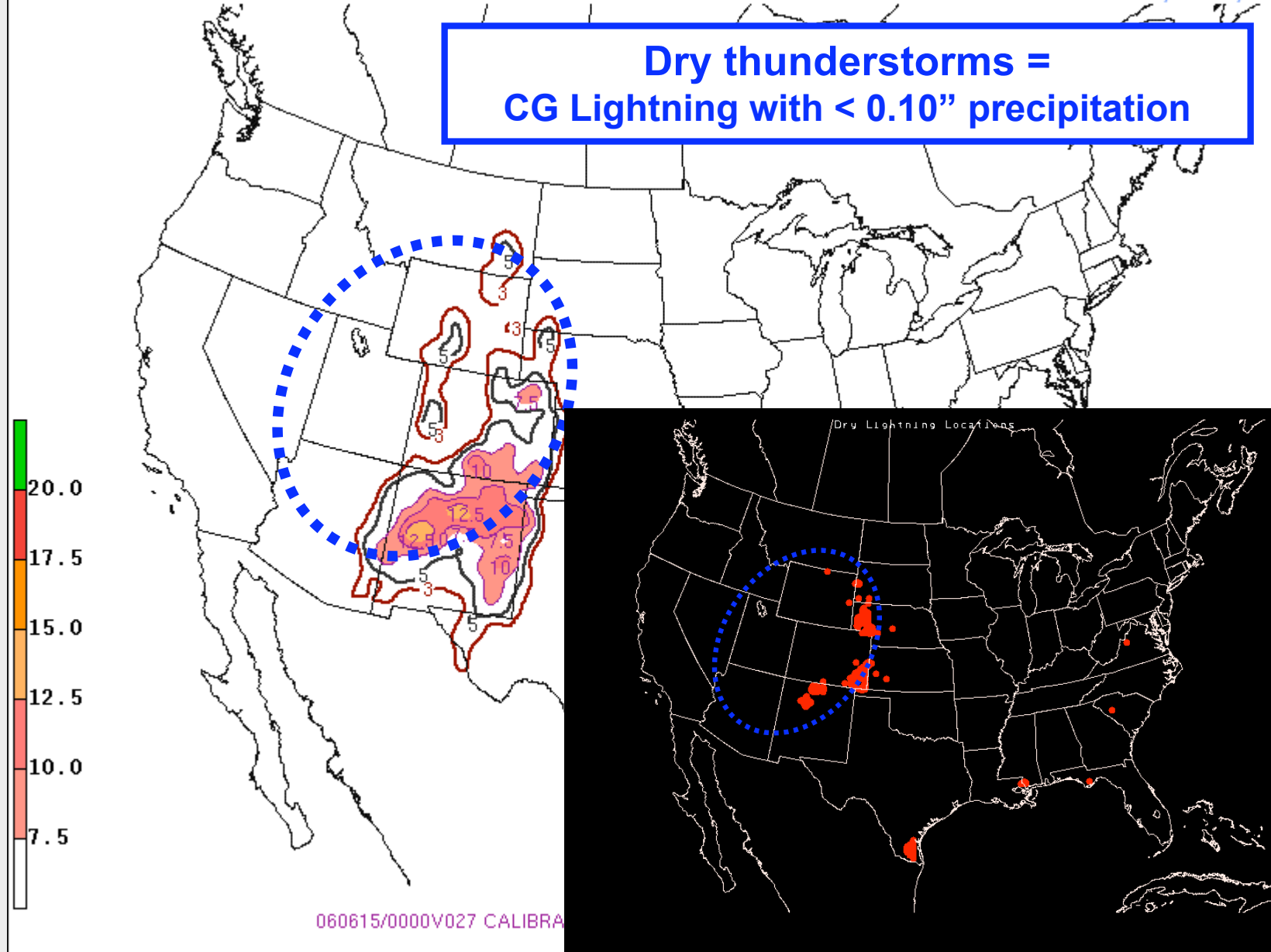


SREF 3h Calibrated Probability of “Dry” Thunderstorms

FCST: F027 VALID: Thu 20060615/0000 UTC

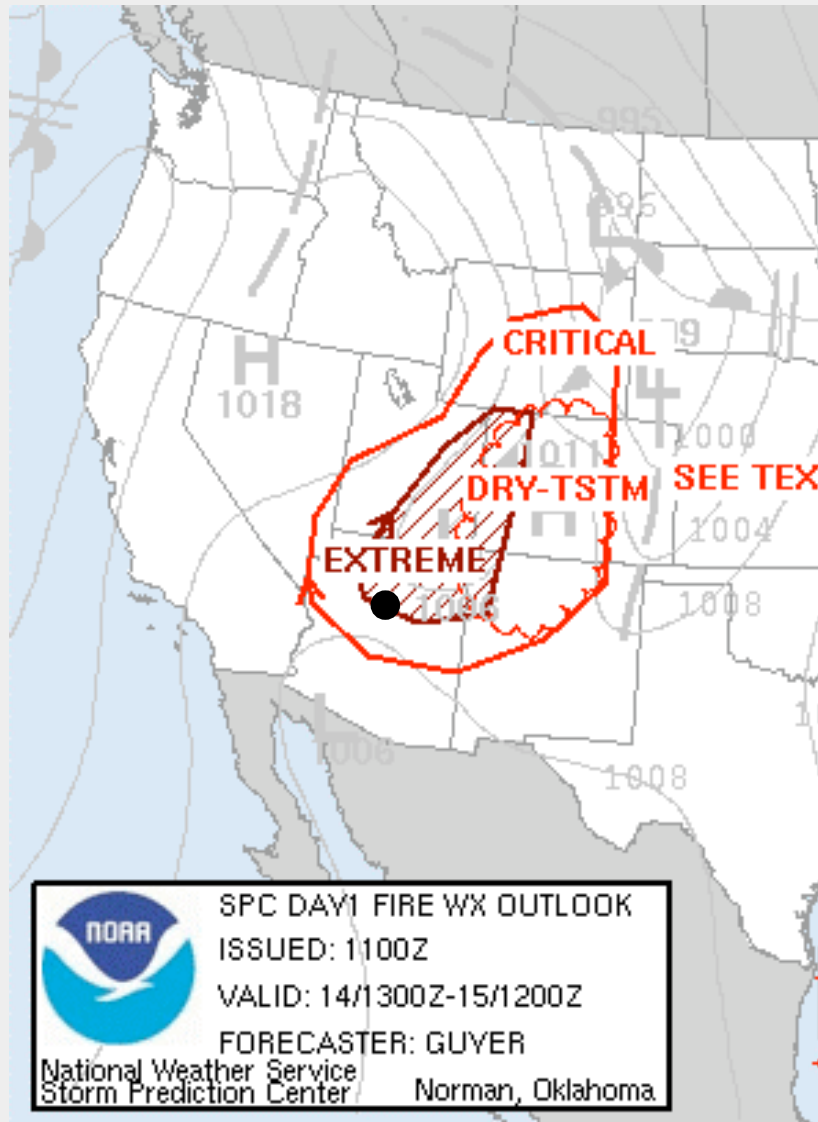
NOAA/NWS Storm Prediction Center, Norman, OK

**Dry thunderstorms =
CG Lightning with < 0.10” precipitation**



SPC Operational Outlook

(Uncertainty communicated in accompanying text)



The Woody Fire burns toward homes Wednesday in Flagstaff, Ariz. The blaze threatened five subdivisions on the west side of Flagstaff, forcing more than 100 homes to evacuate Wednesday night.

Associated Press

Wildfire near Flagstaff forces some evacuations

Associated Press

June 14, 2006

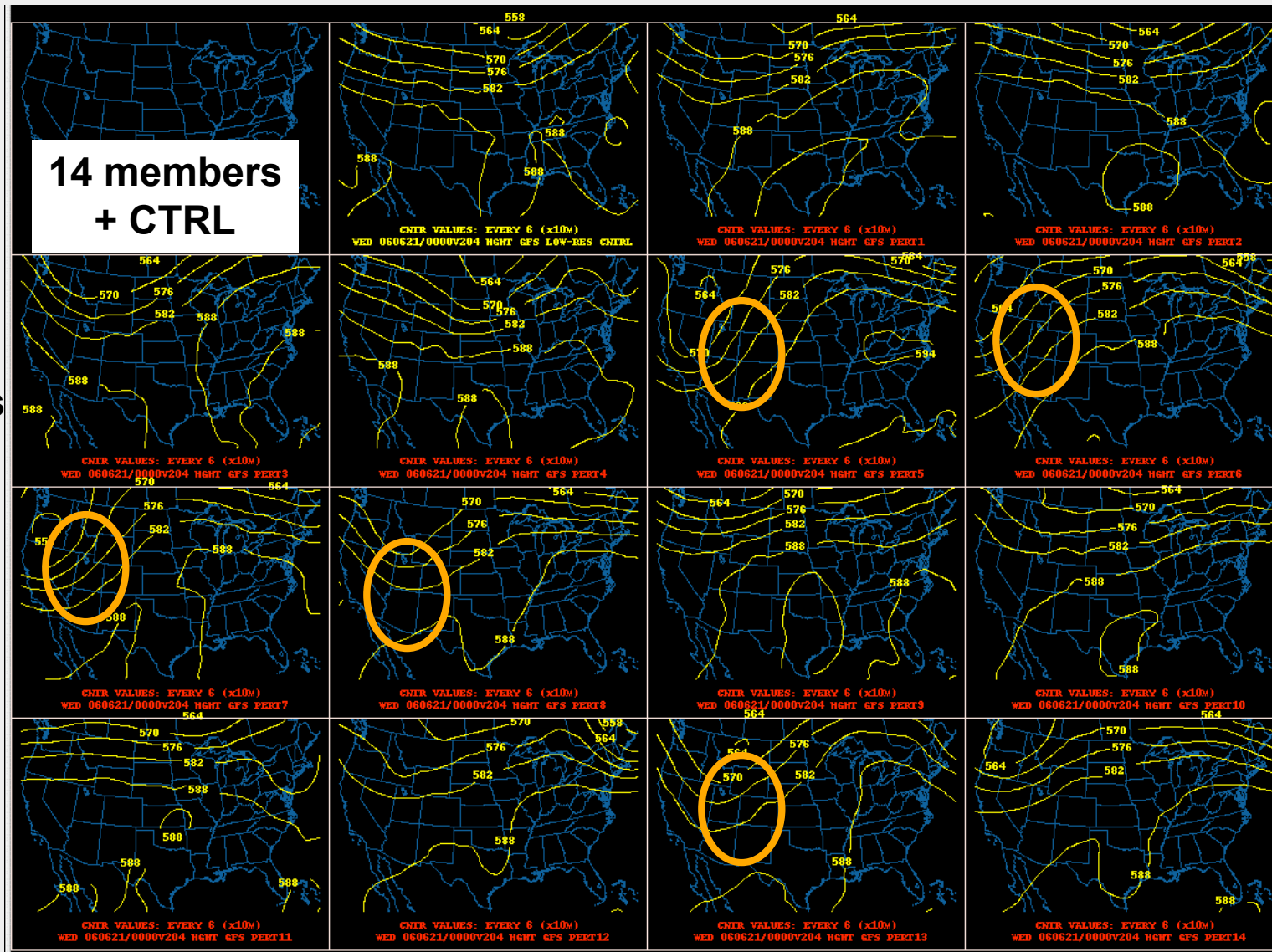
FLAGSTAFF - More than 100 homes remained evacuated Wednesday night as a wind-whipped wildfire threatened five subdivisions on the west side of Flagstaff, sending scores of people to shelters set up by the American Red Cross.

Critical Area
 Critical Area - Dry Tstm
 Extremely Critical Area
Surface Analysis Valid 00Z (Courtesy HPC)

Extended forecast example using “*Postage Stamps*”



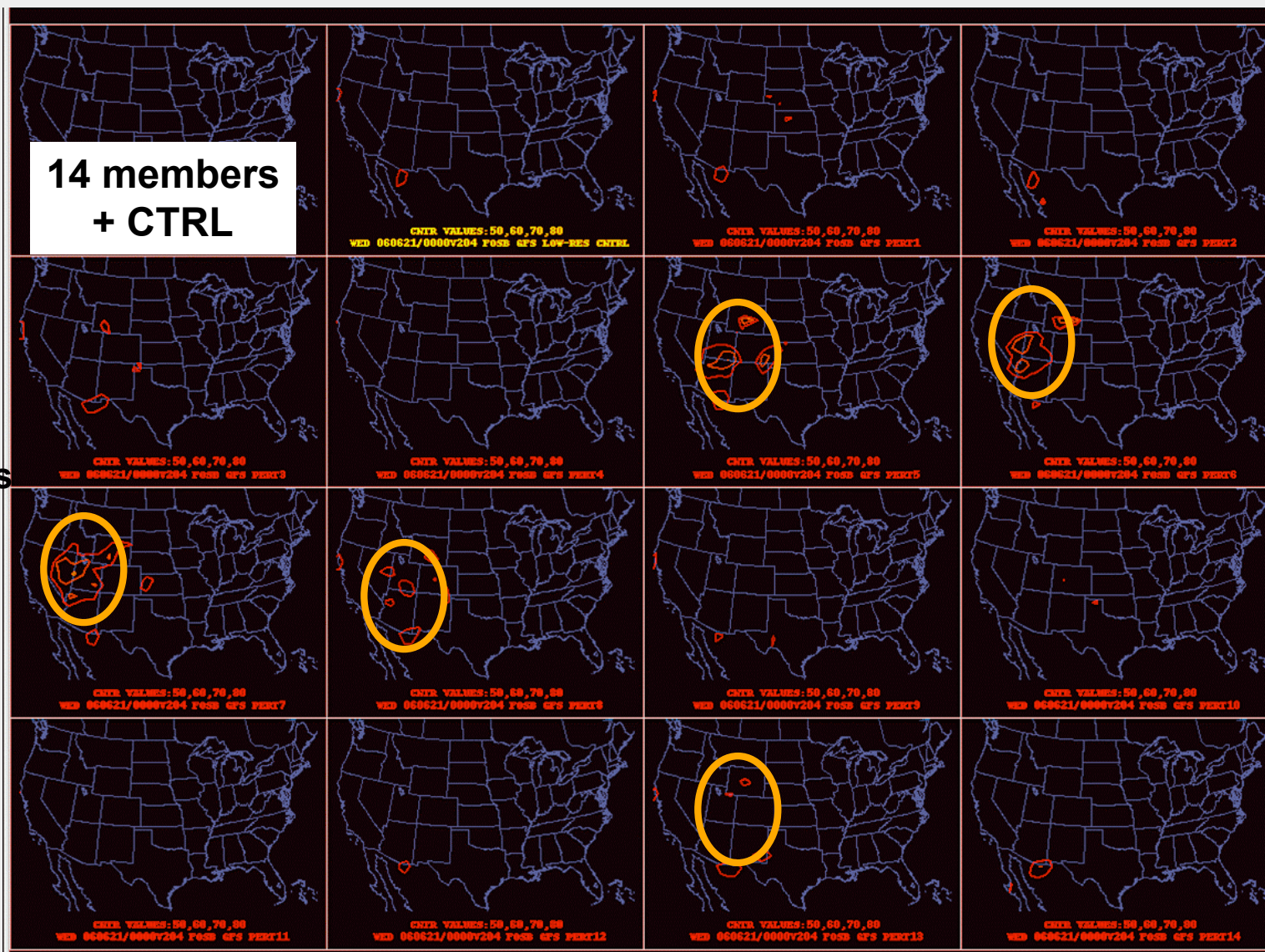
Postage Stamps: 500 mb HGHT



GFS Ensemble at SPC: F216 valid 00 UTC 21 June 2006

Postage Stamps: Fosberg Index

High
Fosberg
Index in
a few
members



GFS Ensemble at SPC: F216 valid 00 UTC 21 June 2006

Outline

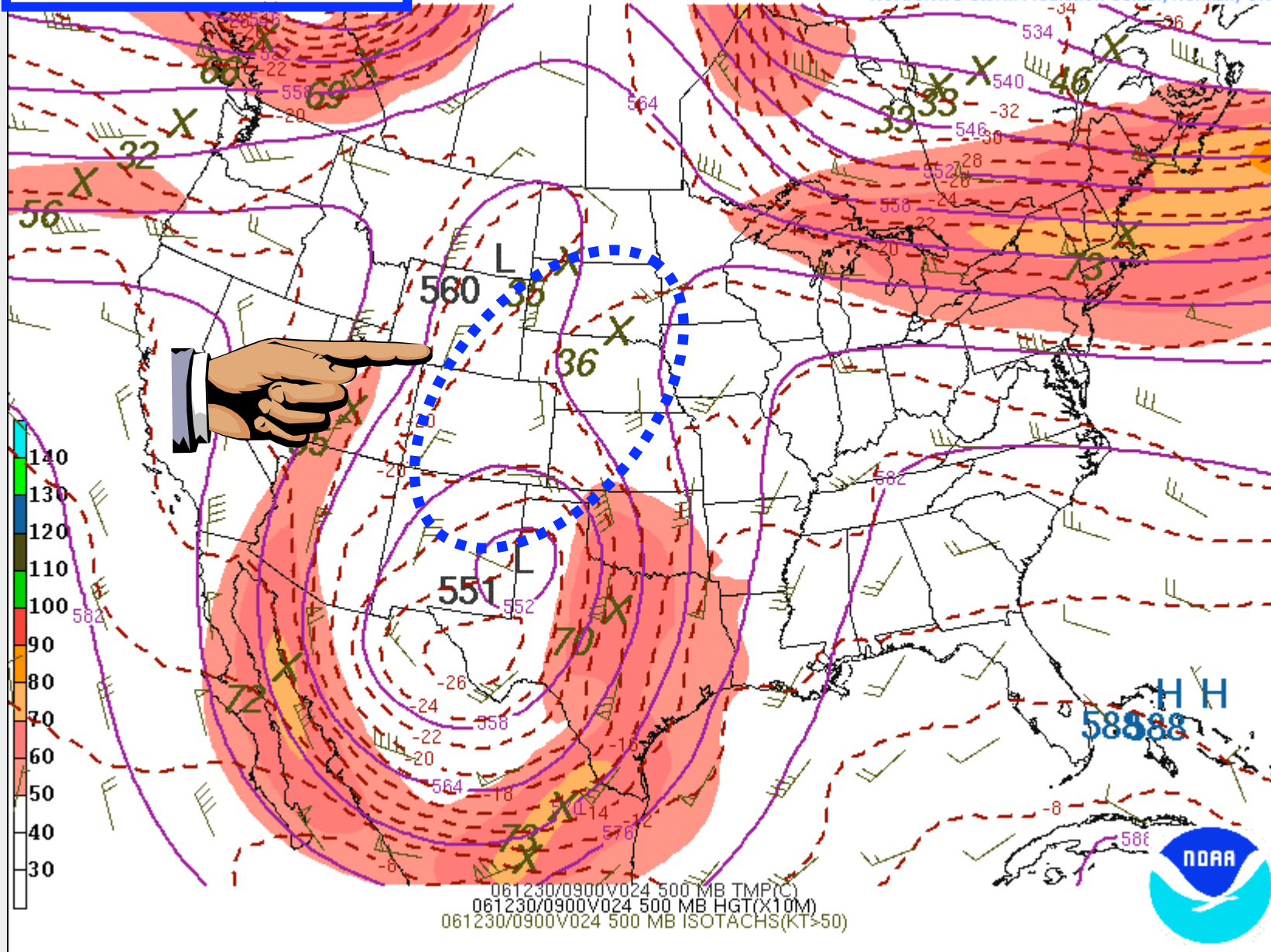
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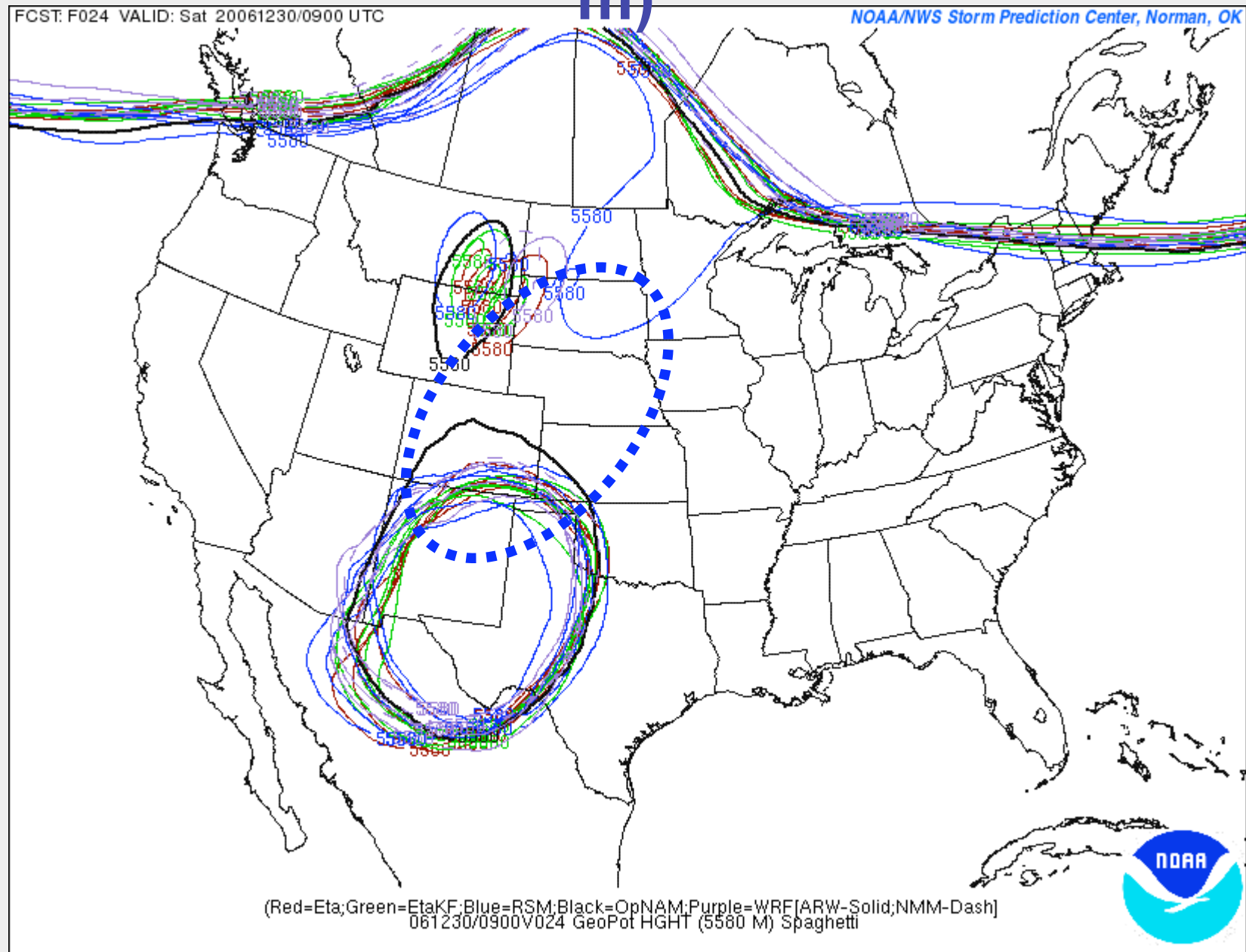
SREF 500 mb Mean Height, Wind, Temp

FCST: F024 VALID: Sat 20061230/0900 UTC

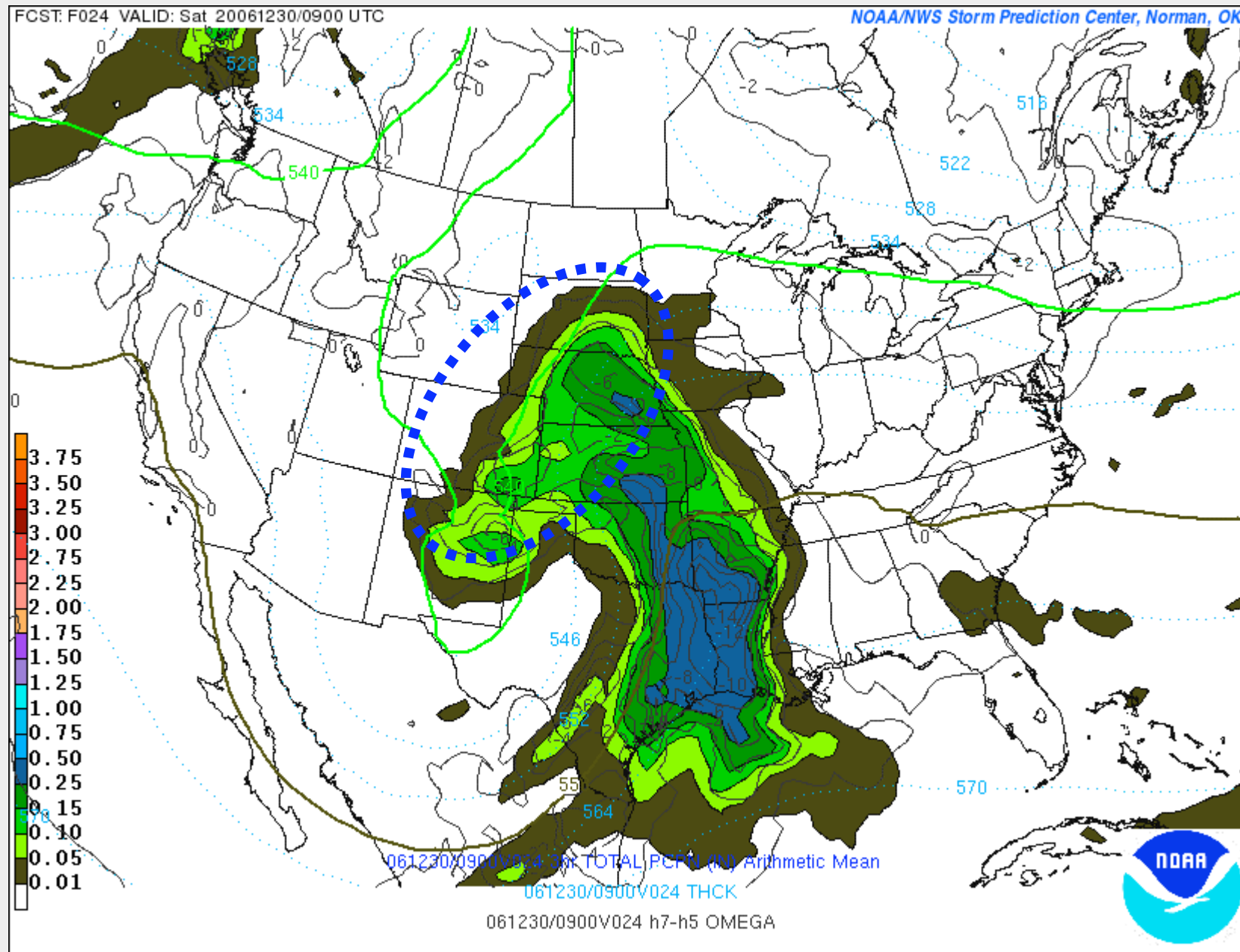
NOAA/NWS Storm Prediction Center, Norman, OK



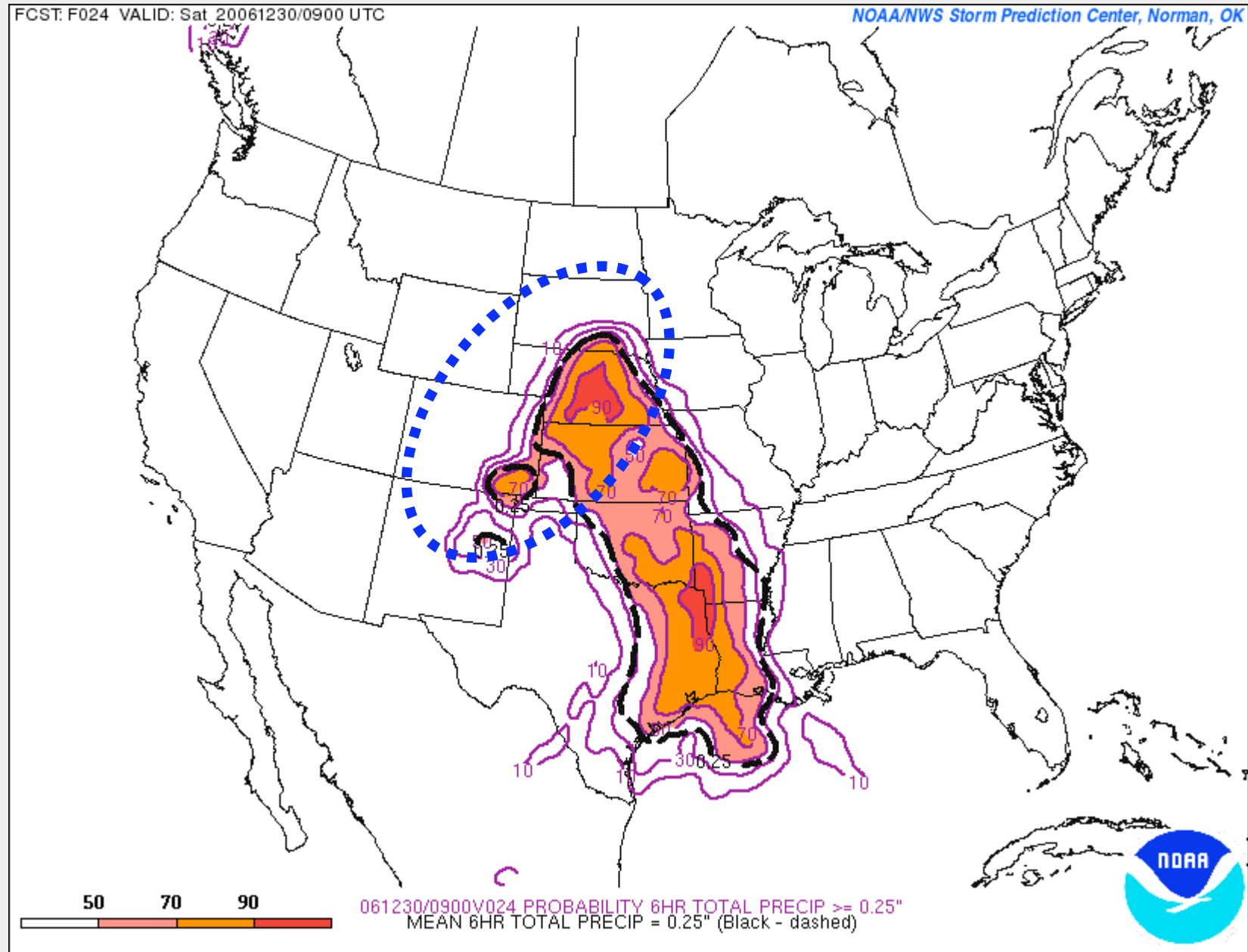
SREF 500 mb Height (Spaghetti = 5580 m)



SREF Mean PCPN, UVV, Thickness



SREF Pr[P06I \geq 0.25"] and Mean P06I = .25" (dash)



Diagnostics and Analysis

- Example: *Dendritic Growth Zone (DGZ)*
 - Very efficient growth (assuming water vapor is replenished)
 - Peak growth rate -14 to -15C in low-to-mid troposphere
 - Accumulate rapidly

Search ensemble members for:

- $\Omega \geq 3$ cm/second
- $-11\text{ C} \leq \text{Temp} \leq -17\text{ C}$
- Layer depth ≥ 50 mb
- RH in layer $\geq 85\%$

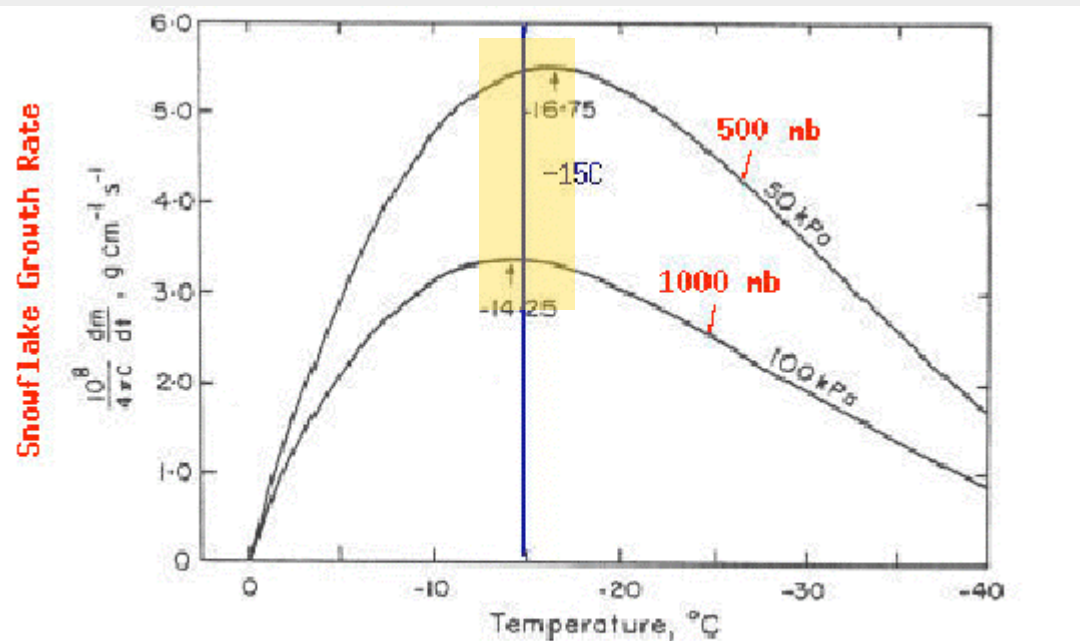
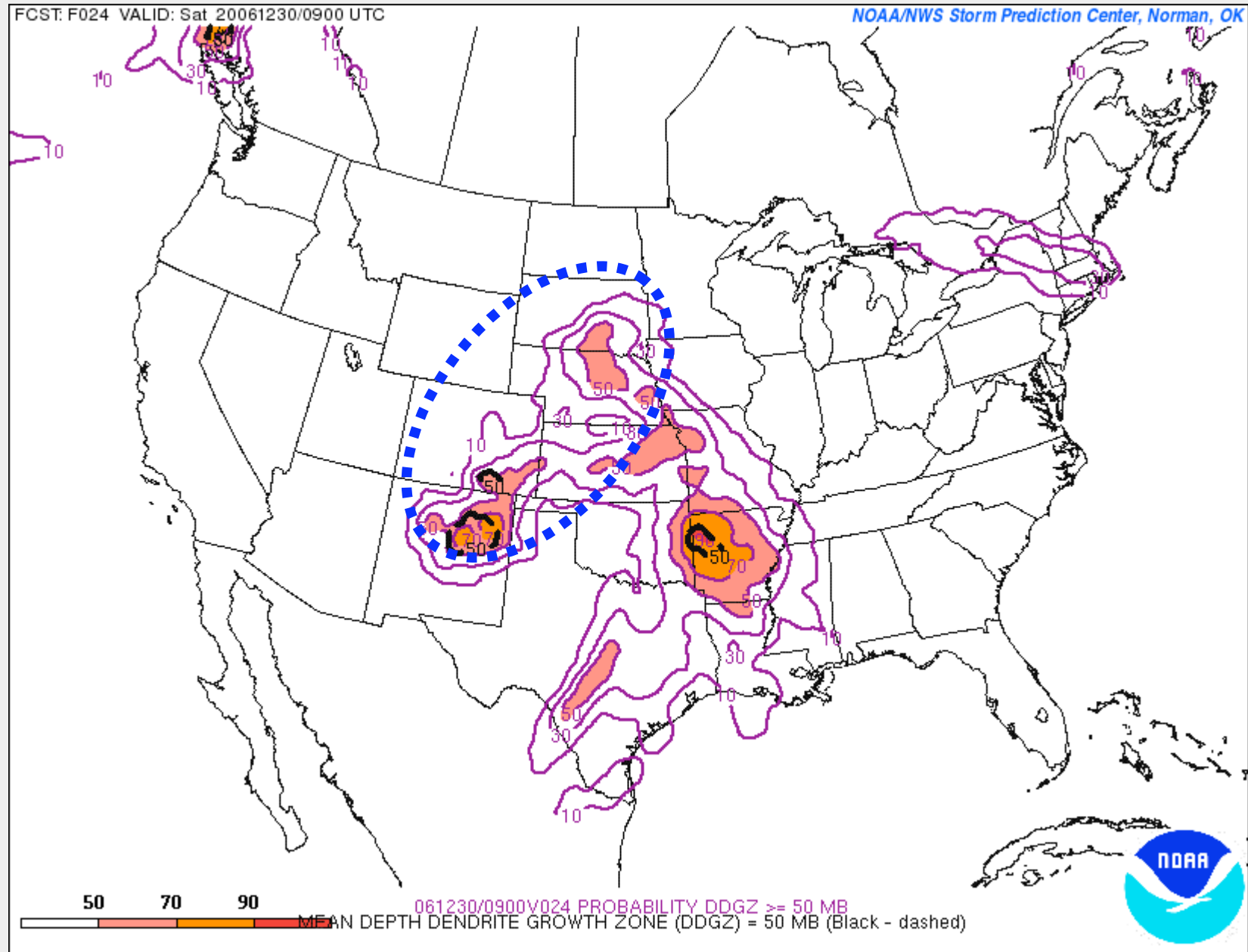
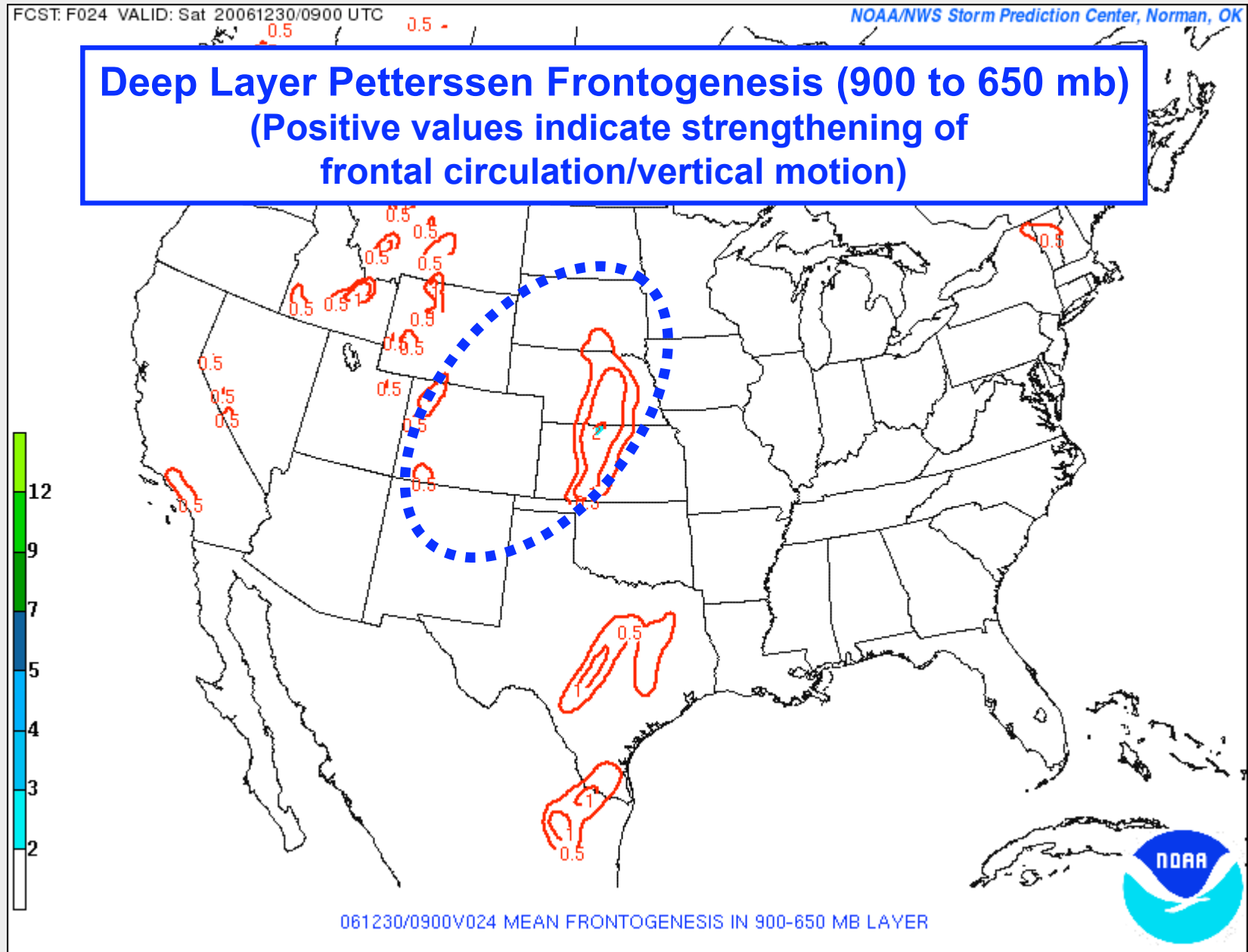


FIG. 9.4. Normalized ice crystal growth rate as a function of temperature. (Adapted from Byers, 1965.)

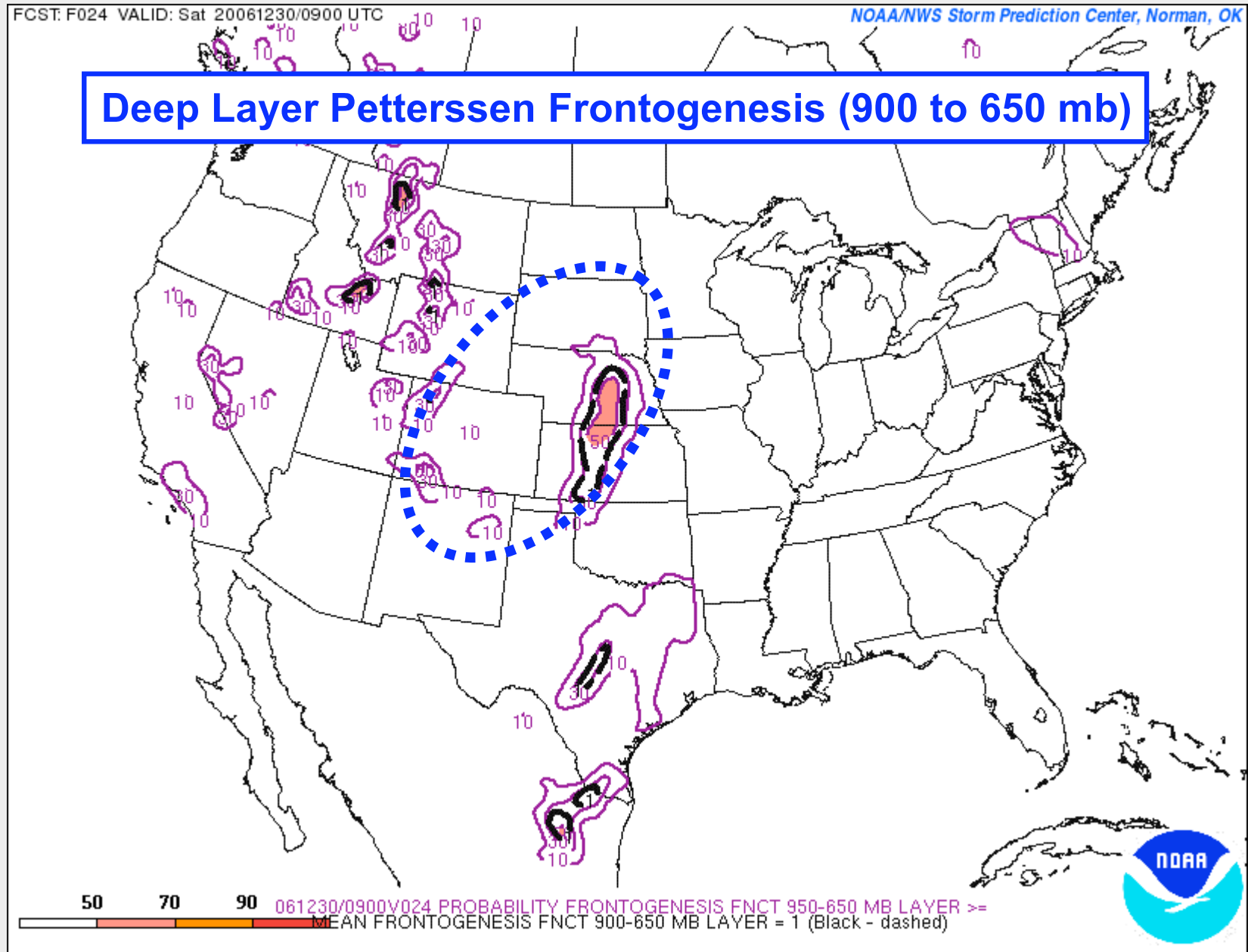
SREF Pr[DGZ \geq 50 mb deep]



SREF Mean 2-D Frontogenesis Function



SREF Pr[2-D Frontogenesis Function] ≥ 1



MPV

Moist Potential Vorticity

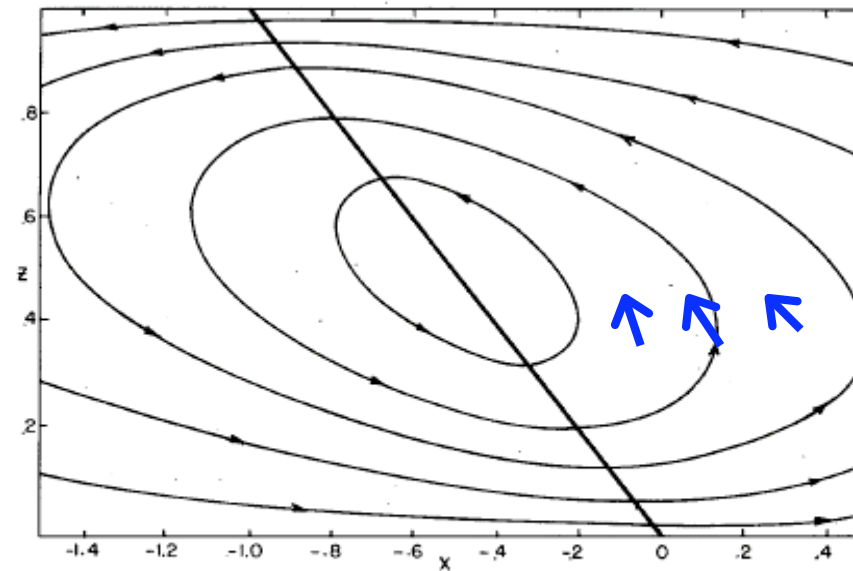


FIG. 4. The cross-front circulation in physical space for the case that $q_1 = 1.0$ and $b = 5.1$. The minimum value of the dimensionless streamfunction is -0.611 ; contours are at 0.1, 0.3, 0.5, 0.7, and 0.9 times the minimum value. The background dimensionless shear equals b . Heavy solid line denotes the position of the $X = 0$ surface.

Typical values
of MPV

AMS (Emanuel 1985)

Enhancement in the
upward branch of the
frontal circulation in
the presence of low
MPV.

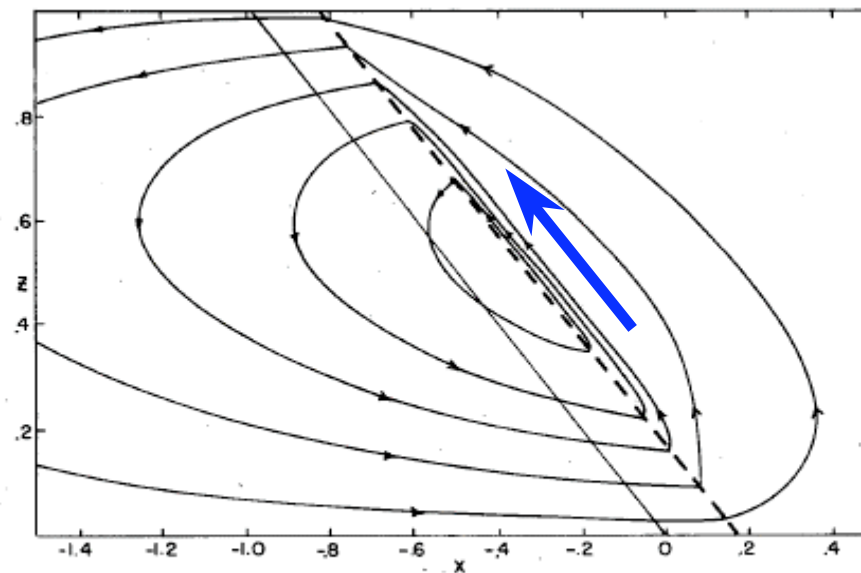
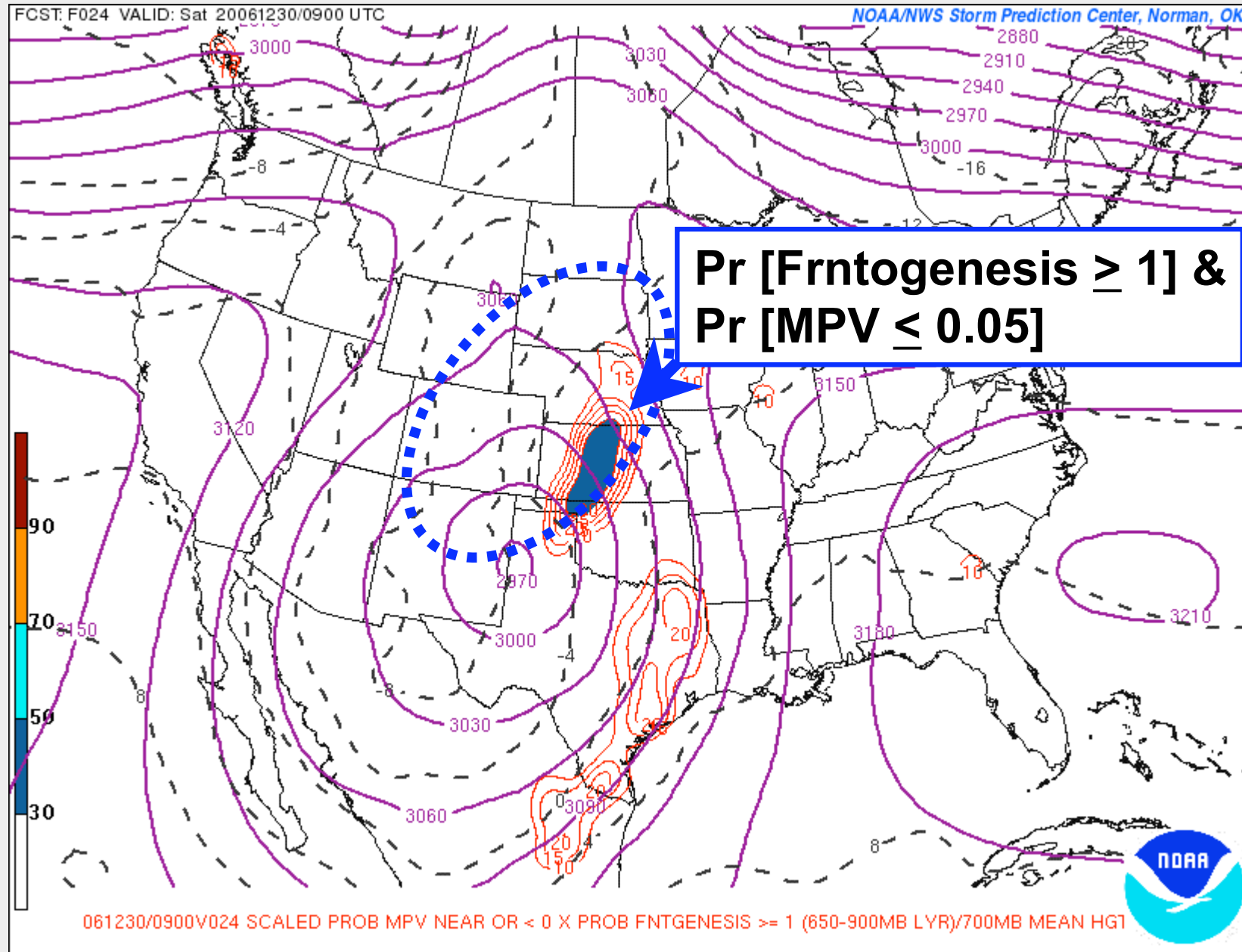


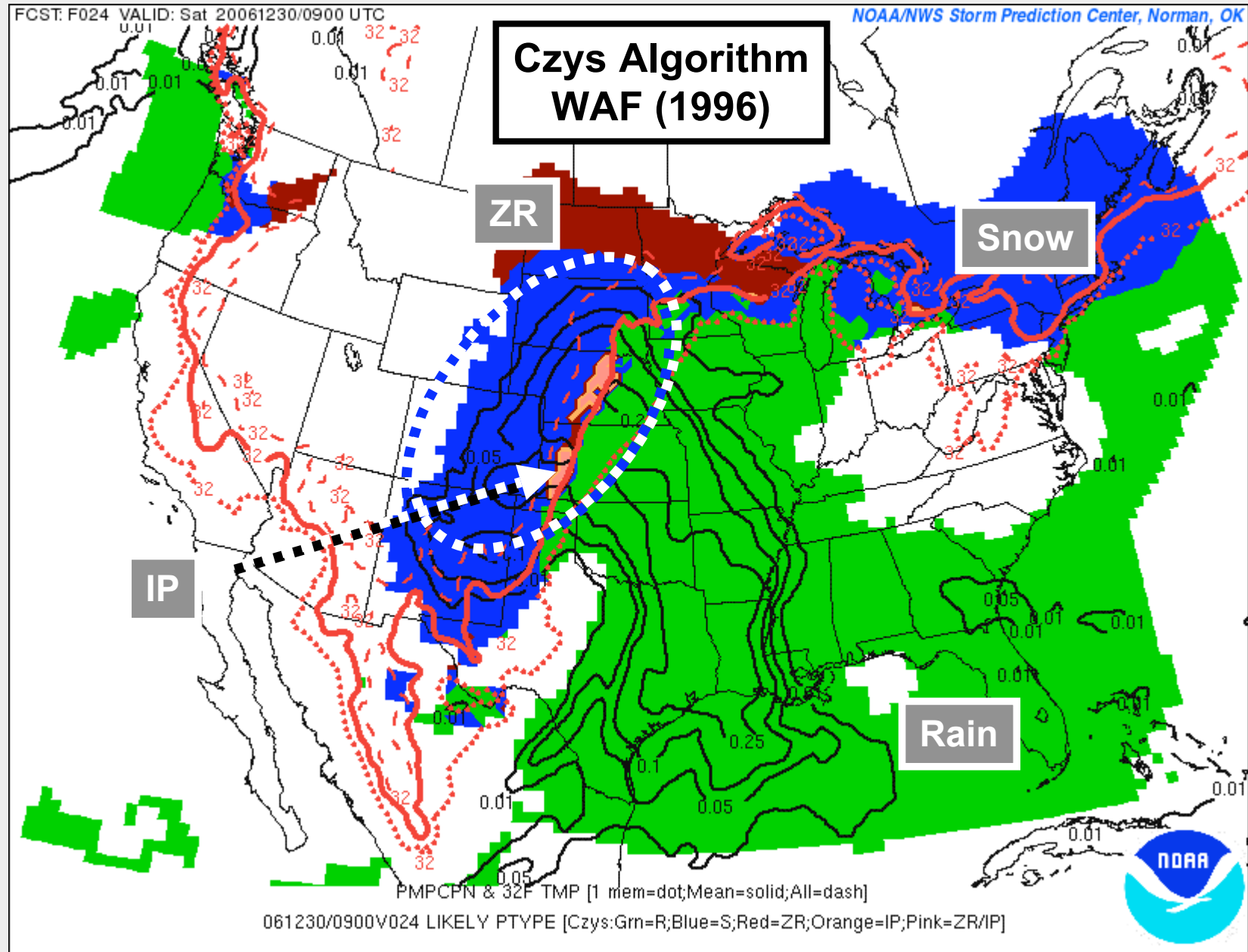
FIG. 5. As in Fig. 4 but for $q_1 = 10^{-2}$. The minimum value of the streamfunction is -1.769 in this case and the heavy dashed line denotes the surface $X = L$.

Low values
of MPV

SREF Combined or Joint Probability



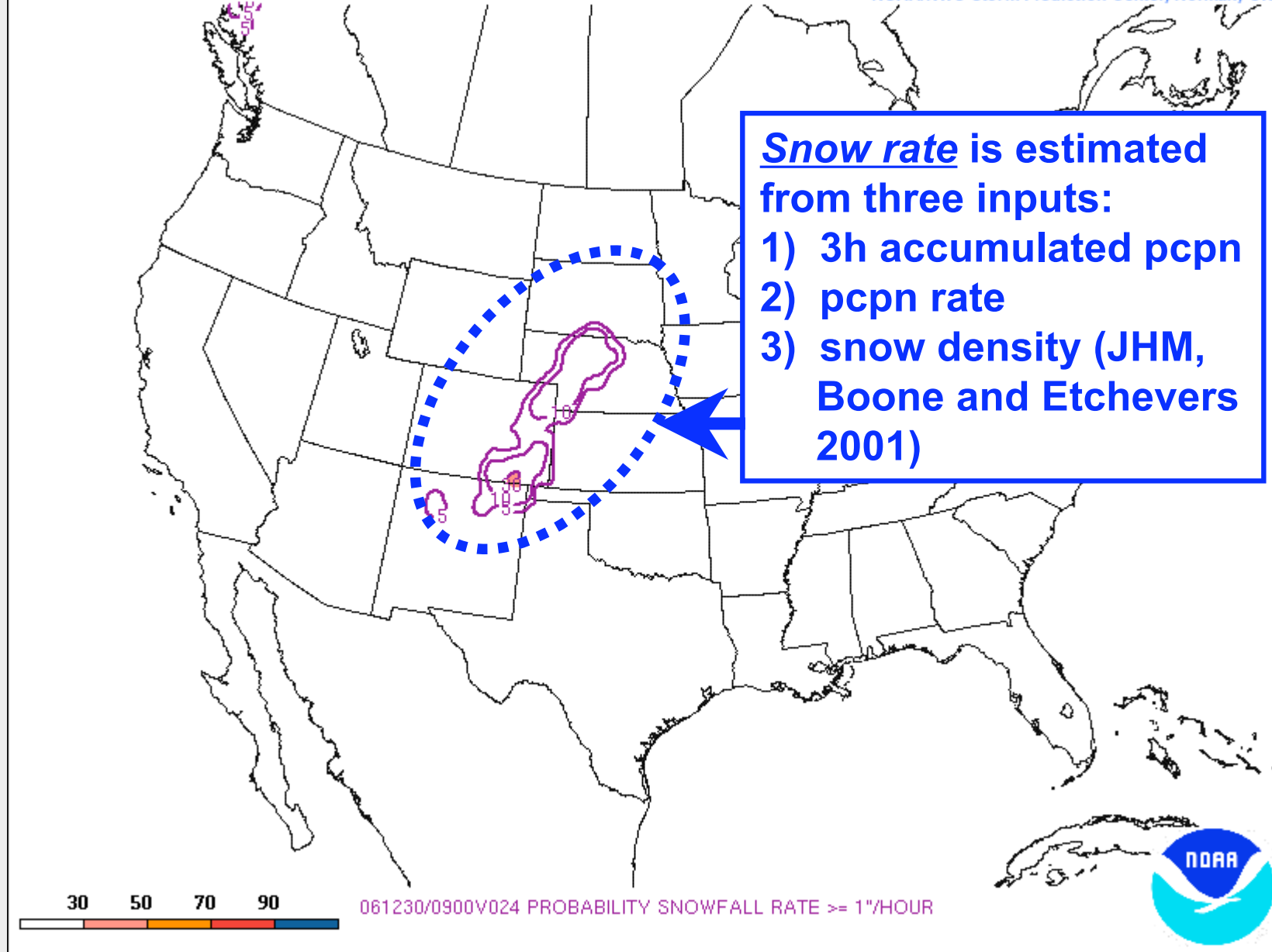
SREF Likely PTYPE and Mean P03I (contours)



SREF Pr[Snowfall Rate ≥ 1 "/hour]

FCST: F024 VALID: Sat 20061230/0900 UTC

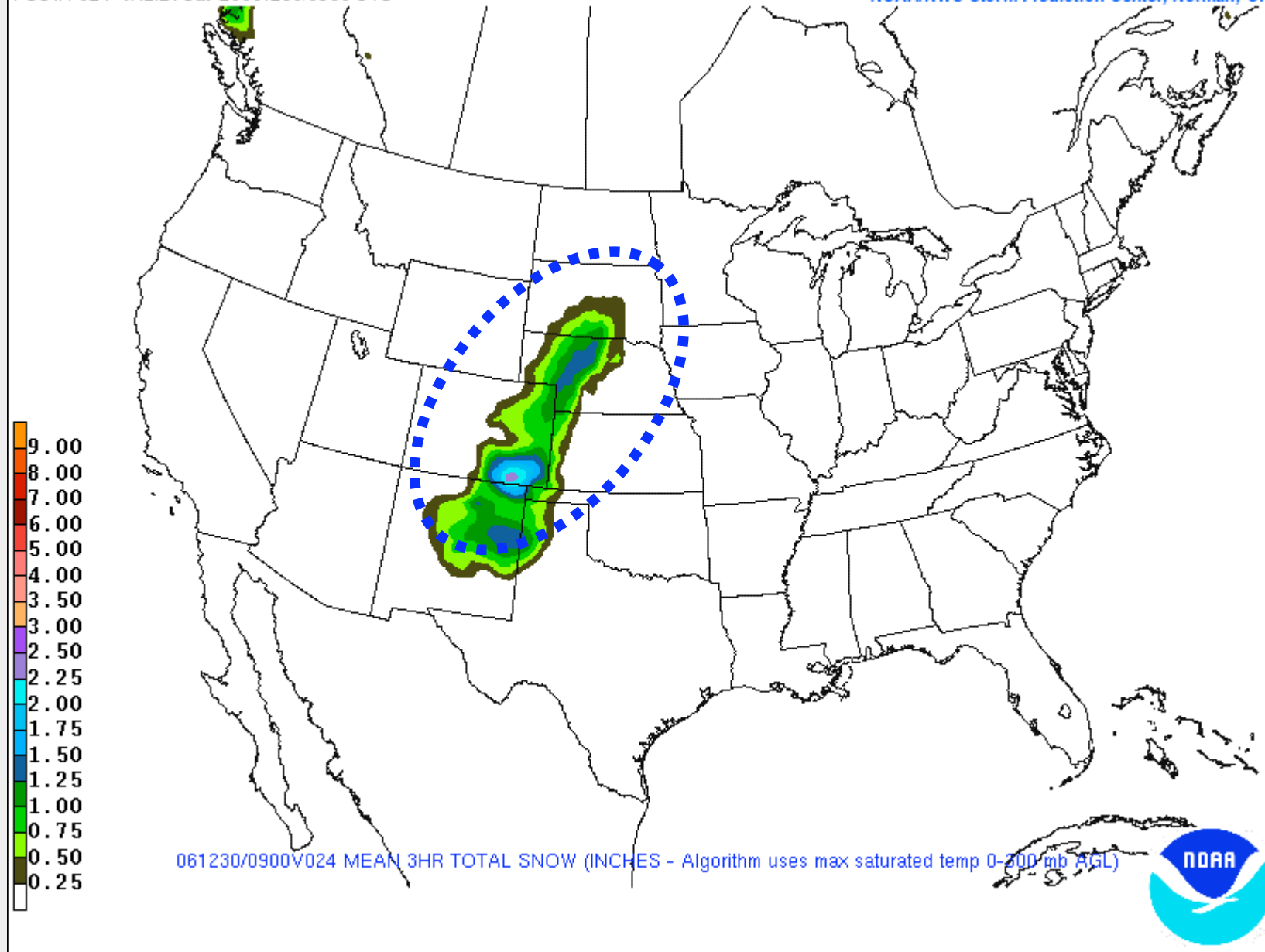
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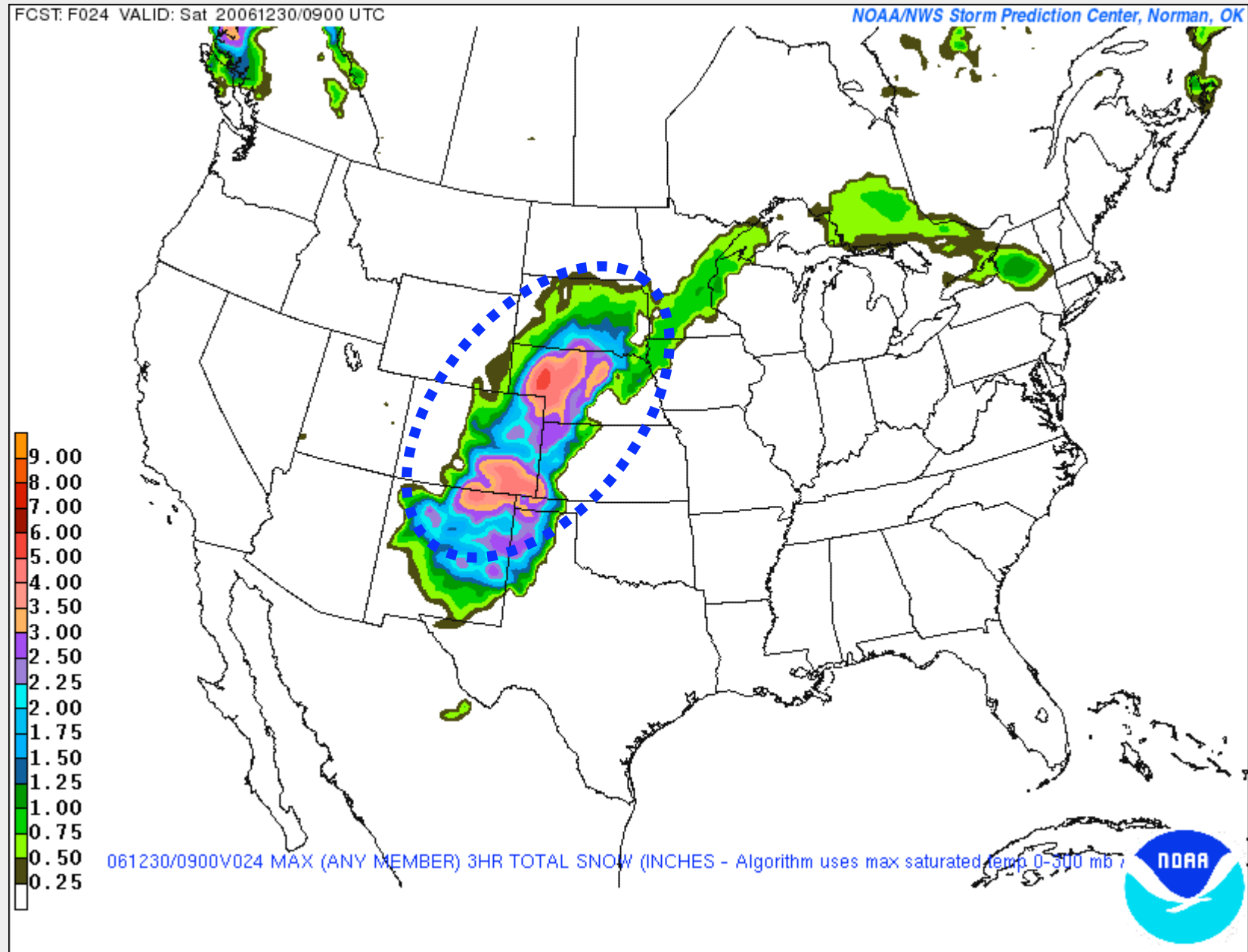
SREF Mean 3h Accumulated Snowfall

FCST: F024 VALID: Sat 20061230/0900 UTC

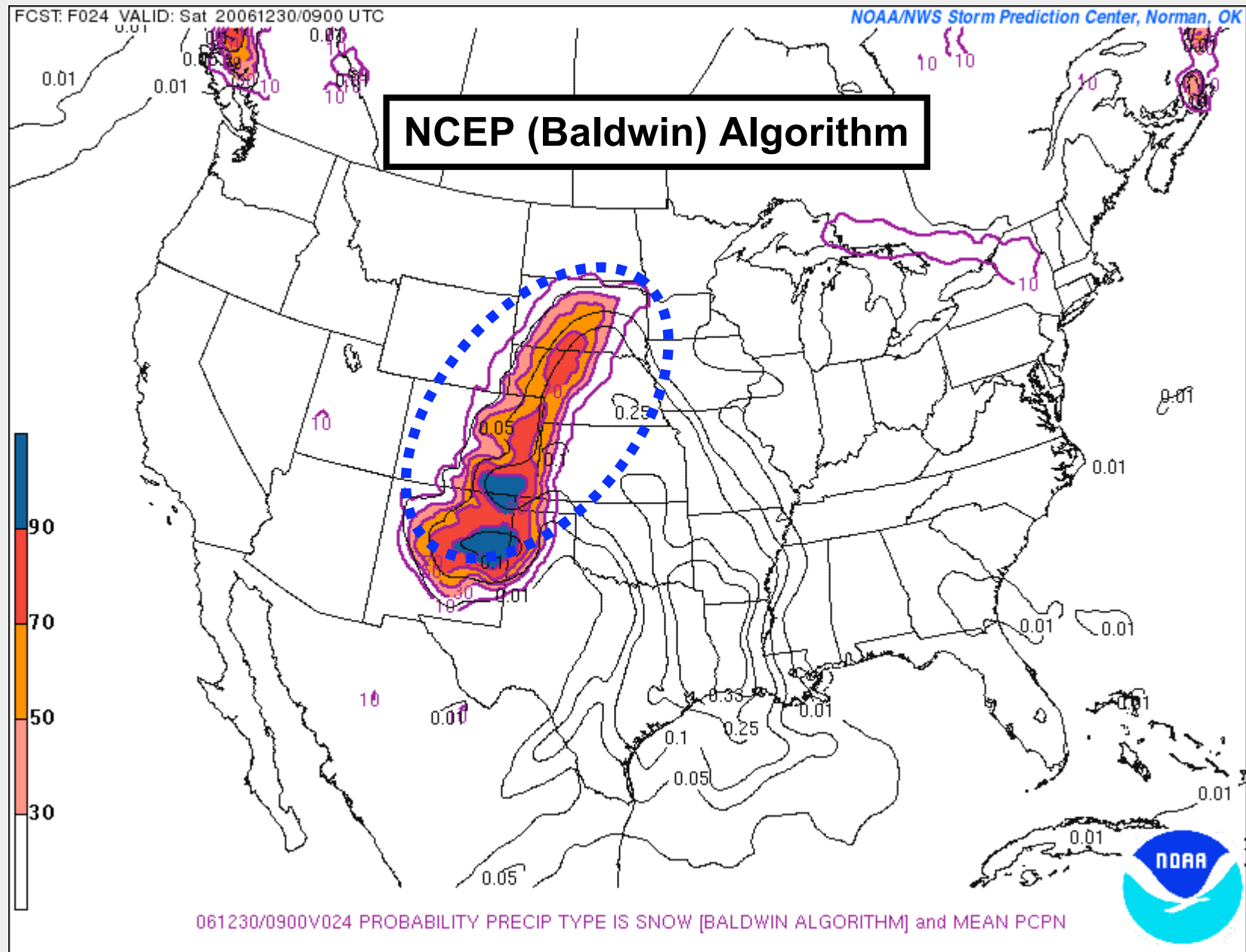
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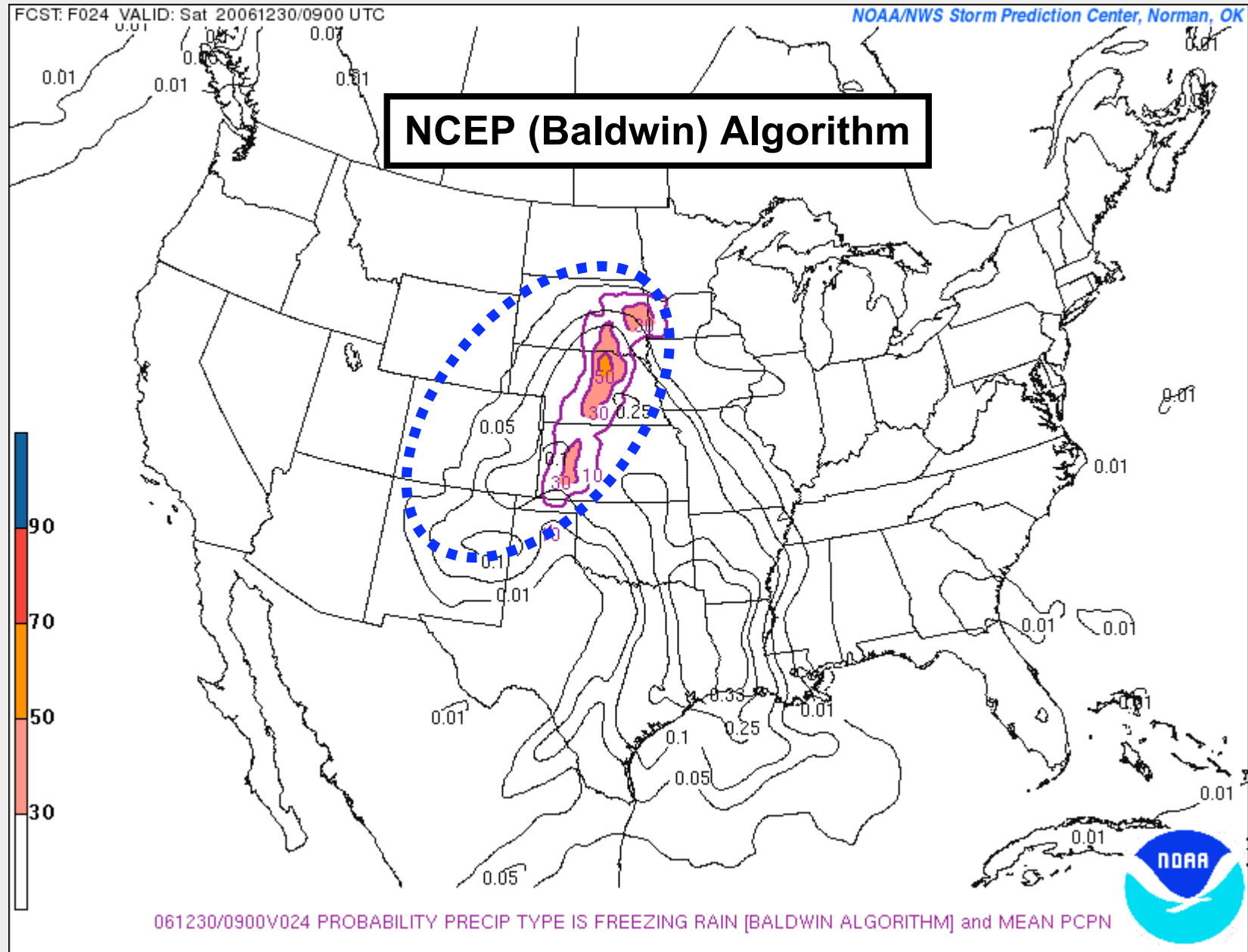
SREF *Maximum* (any member) 3h Accumulated Snowfall



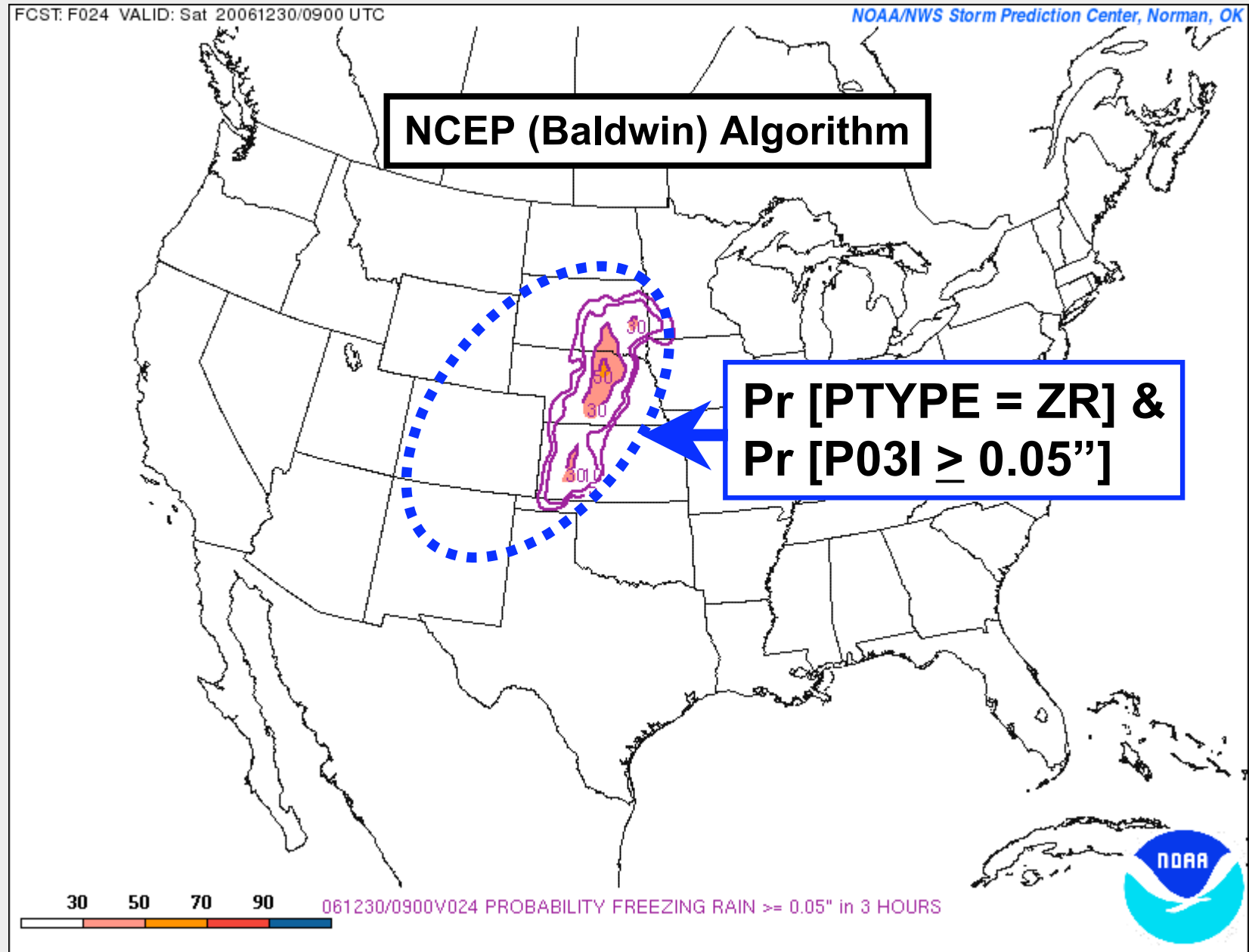
SREF Pr[Ptype = Snow] and Mean P03I (contours)



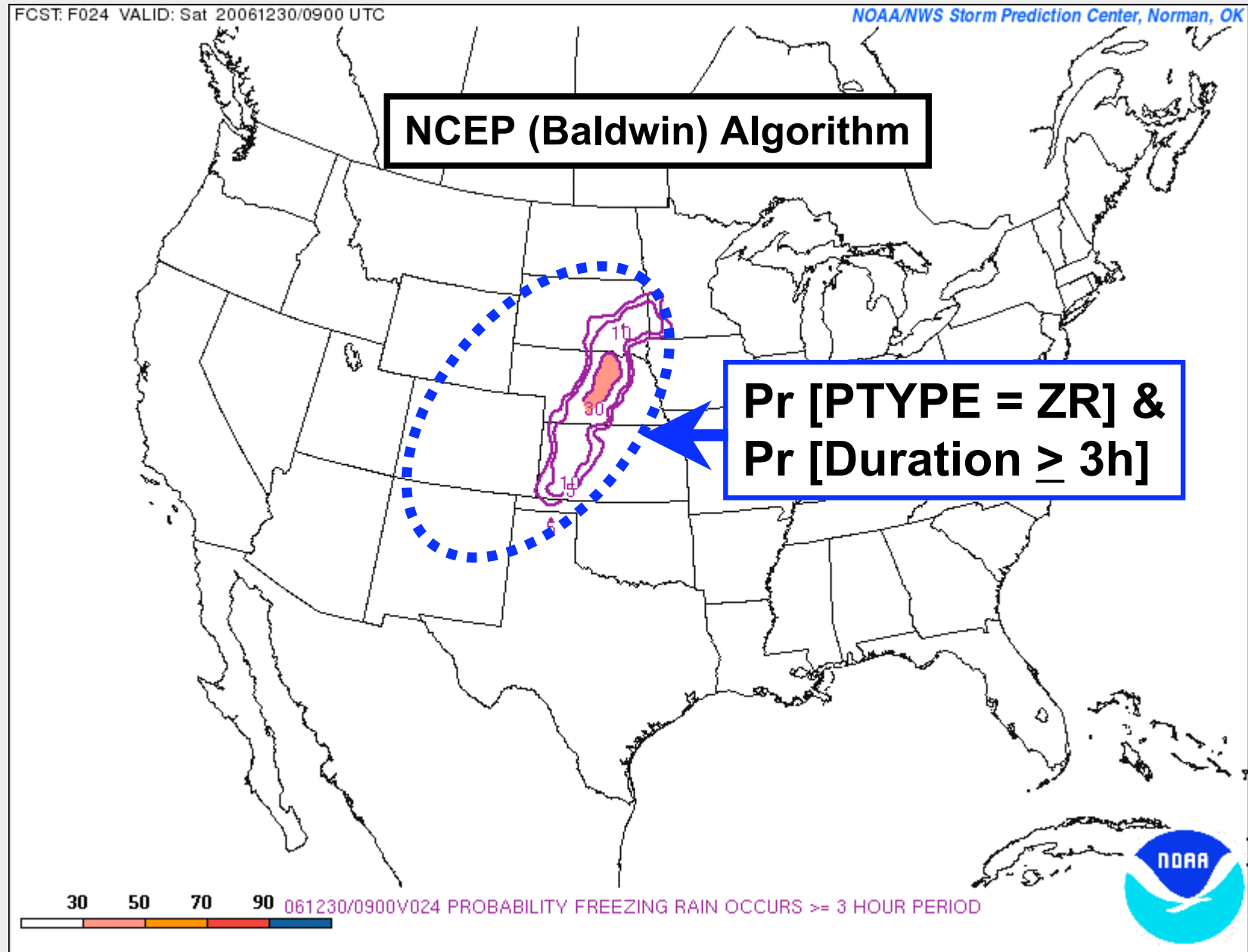
SREF Pr[Ptype = ZR] and Mean P03I (contours)



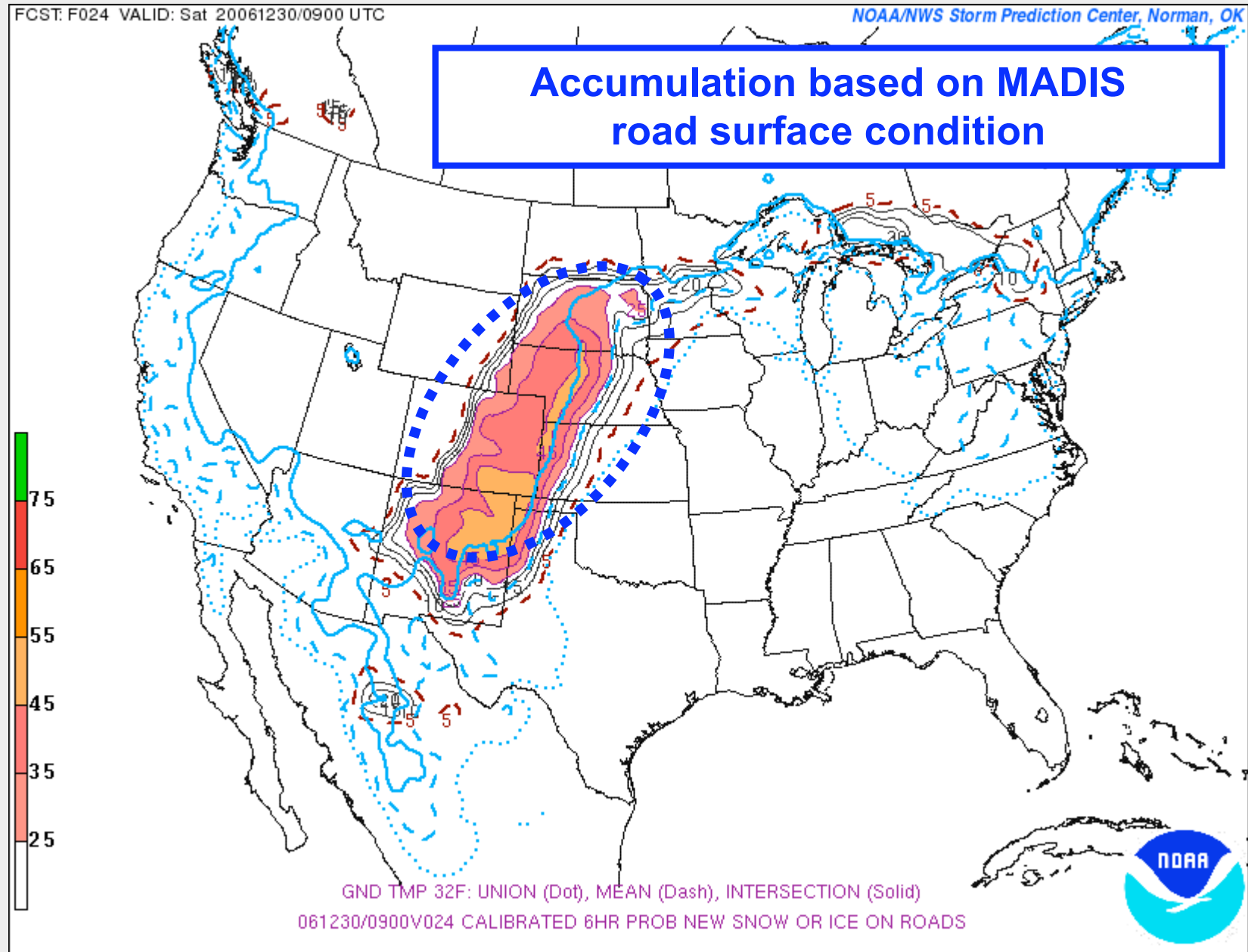
SREF Combined or Joint Probability



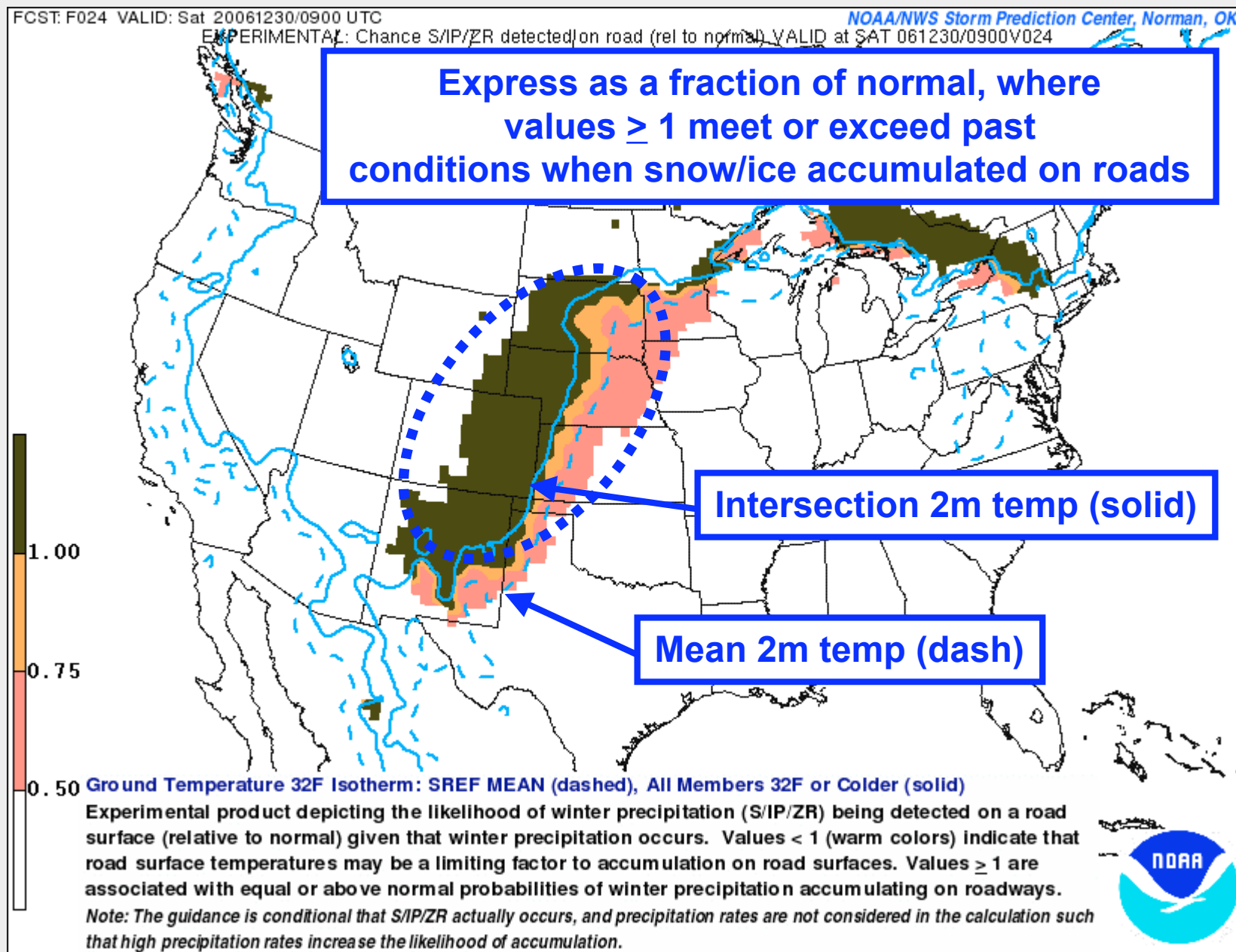
SREF Combined or Joint Probability



SREF 6h Calibrated Probability of Snow/Ice Accum

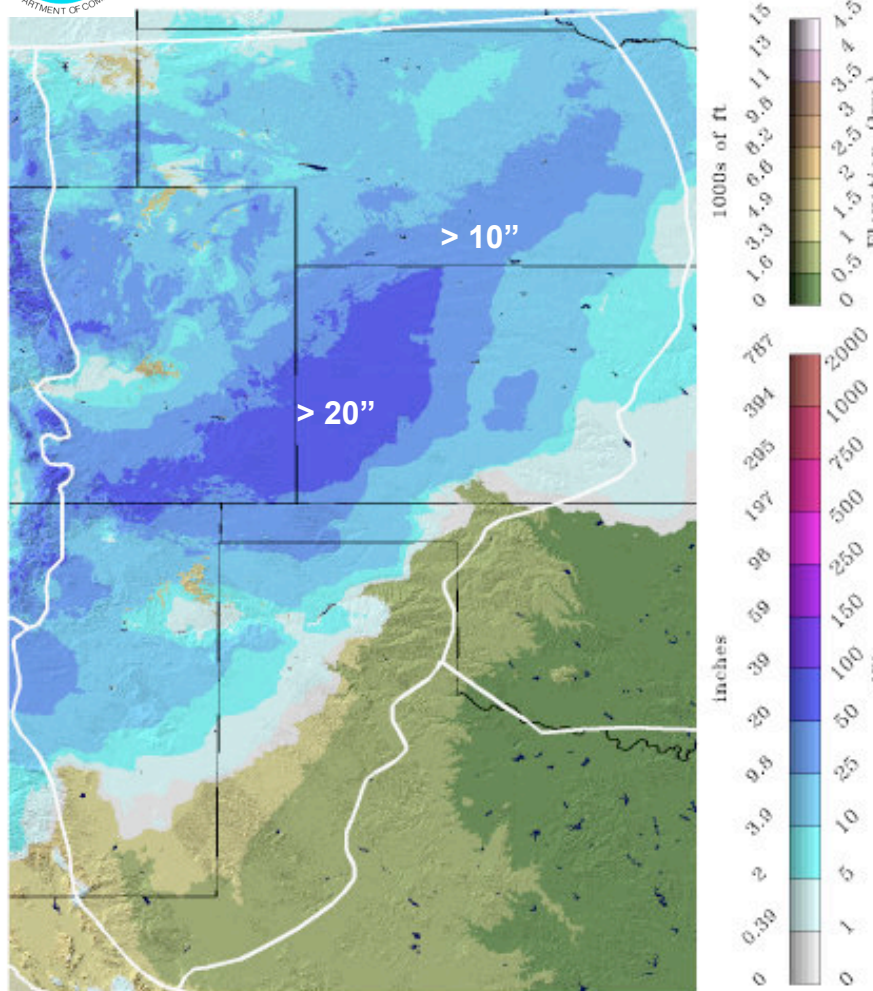


SREF Relative to Normal for Snow/Ice Accumulation





Snow Depth 2007-01-01 06



NOHRSC

**NATIONAL SNOW 2006-
ANALYSIS 2007**

**> 20" snow across large portion
of CO and KS**

> .5" to 1" ZR wrn KS, wrn/cntrl NE

Outline

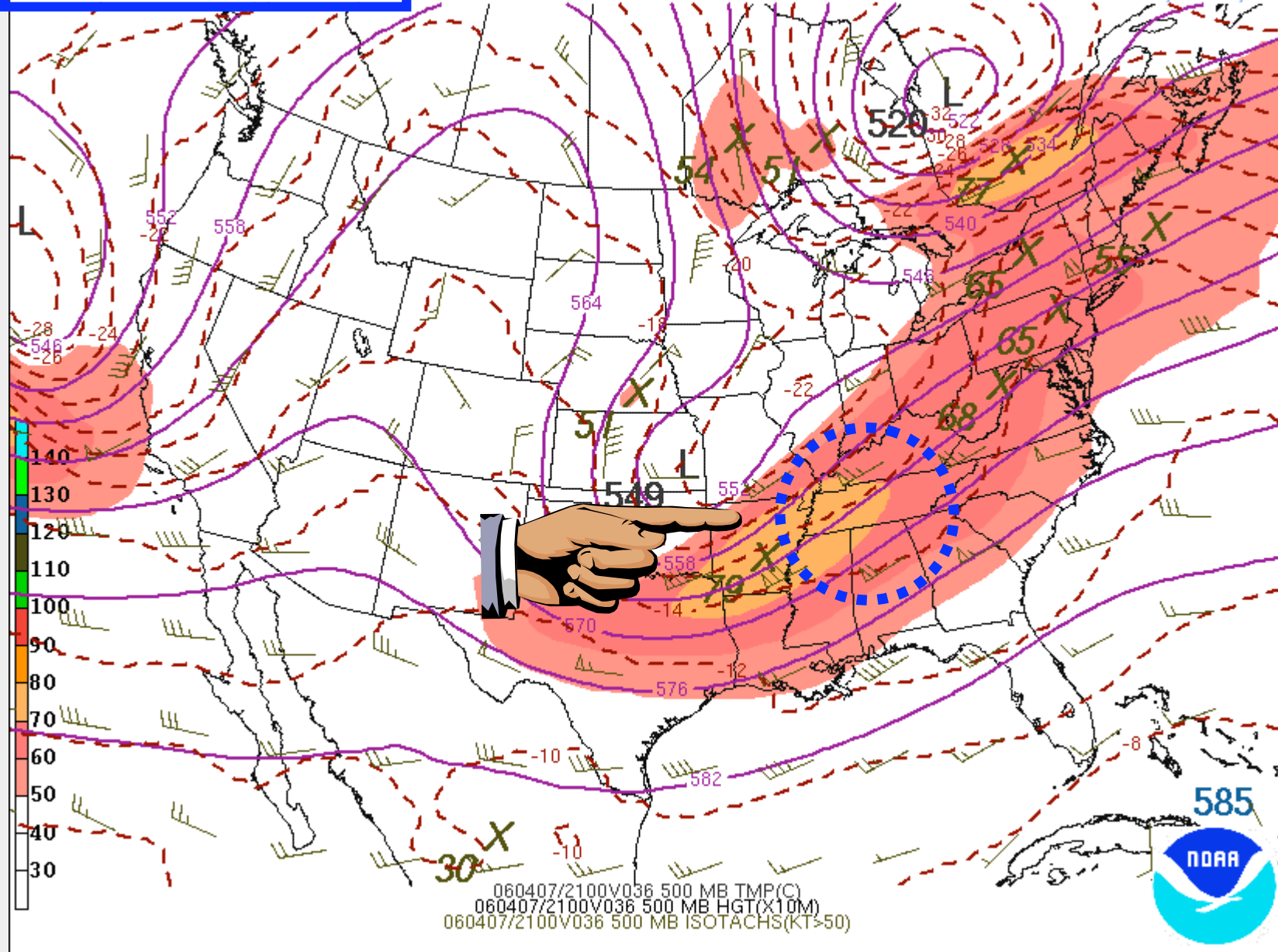
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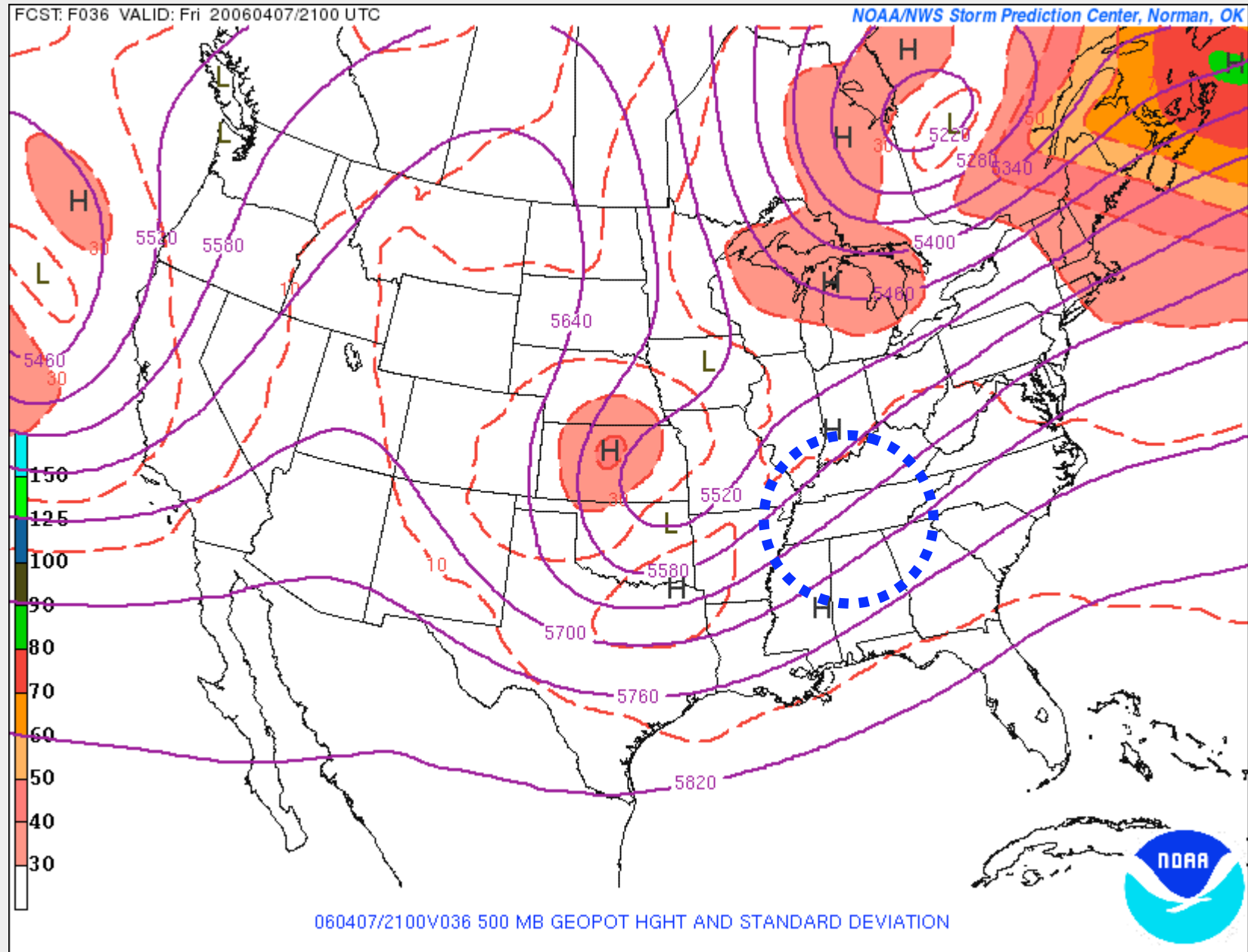
SREF 500 mb Mean Height, Wind, Temp

FCST: F036 VALID: Fri 20060407/2100 UTC

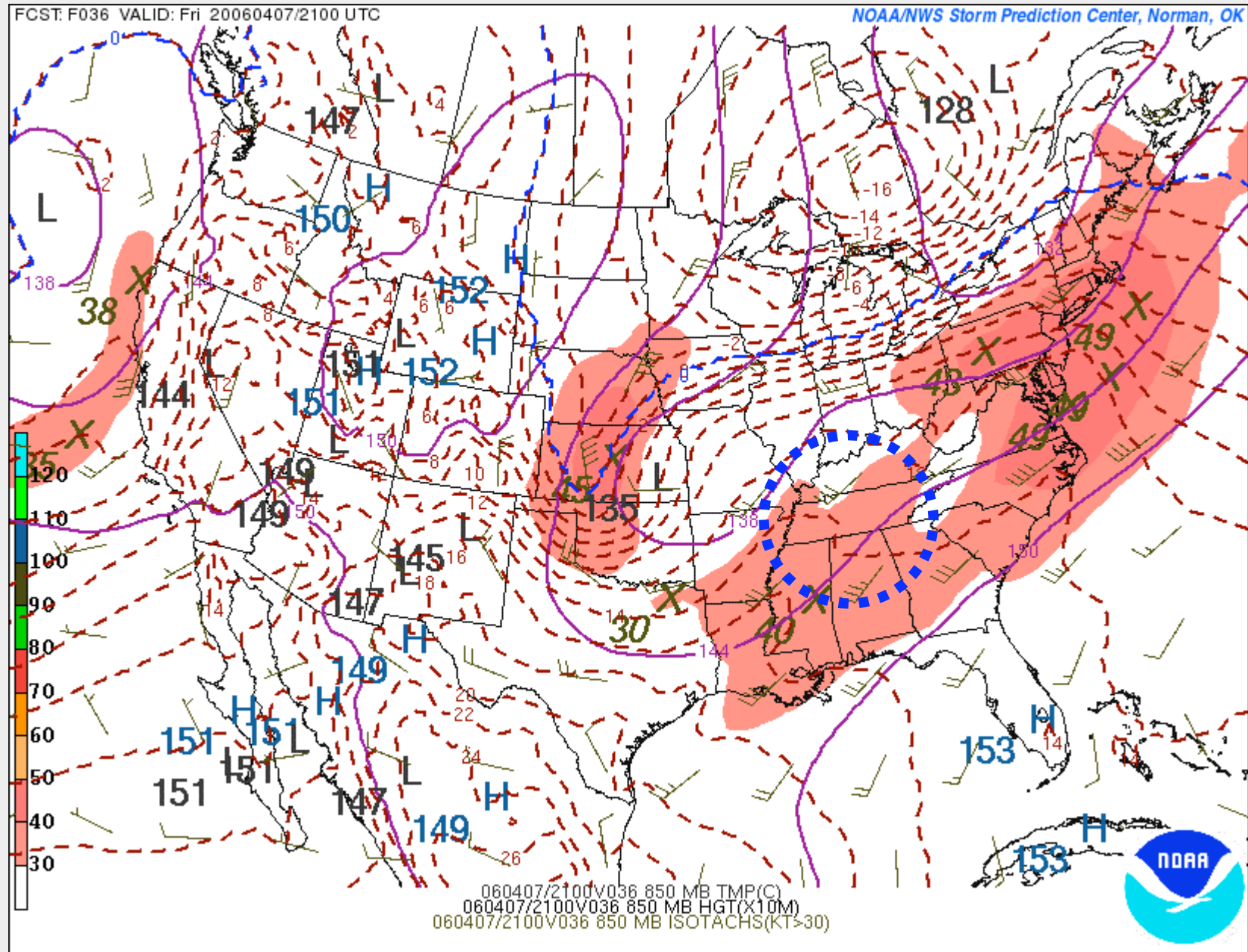
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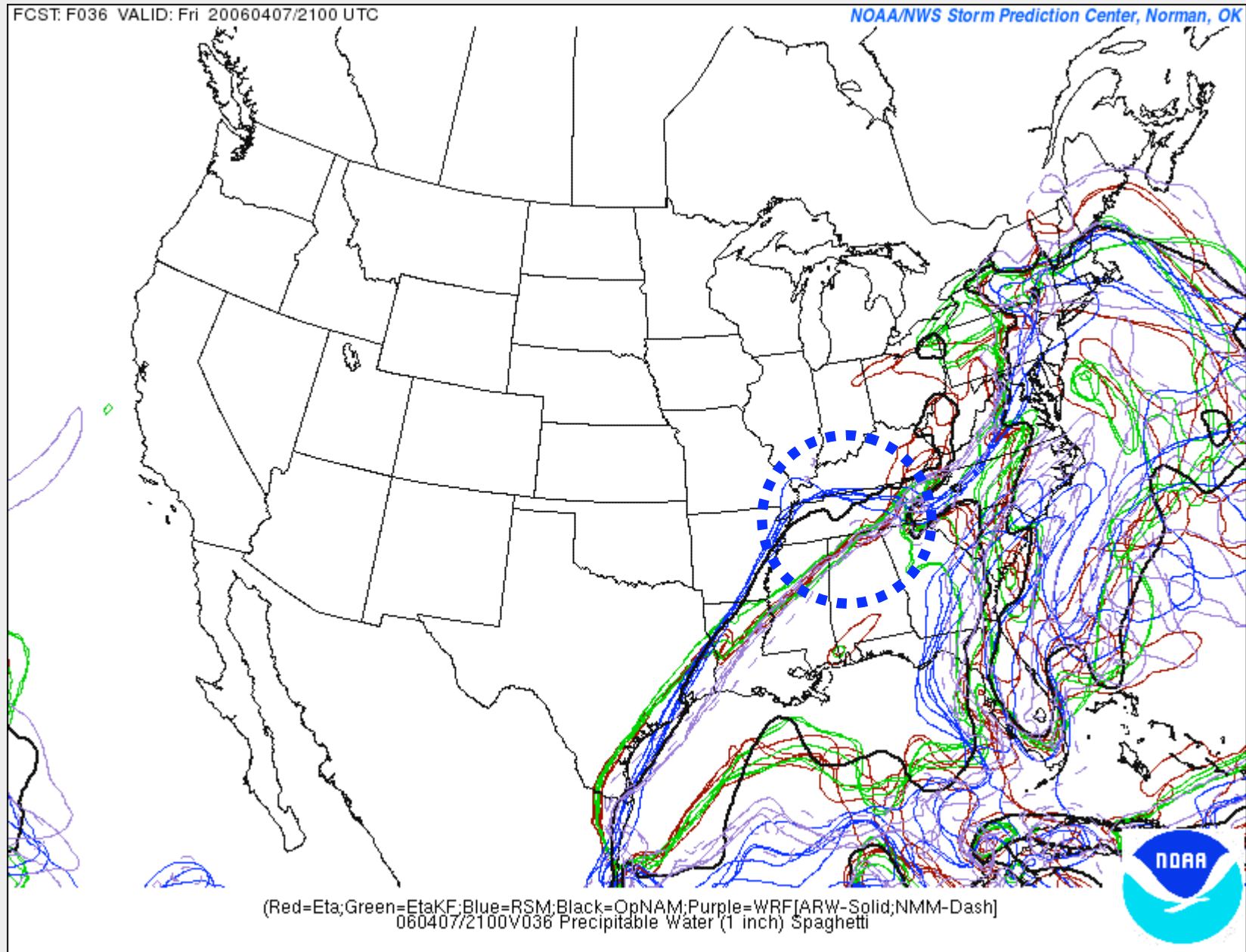
SREF 500 mb Mean Height and SD (dash)



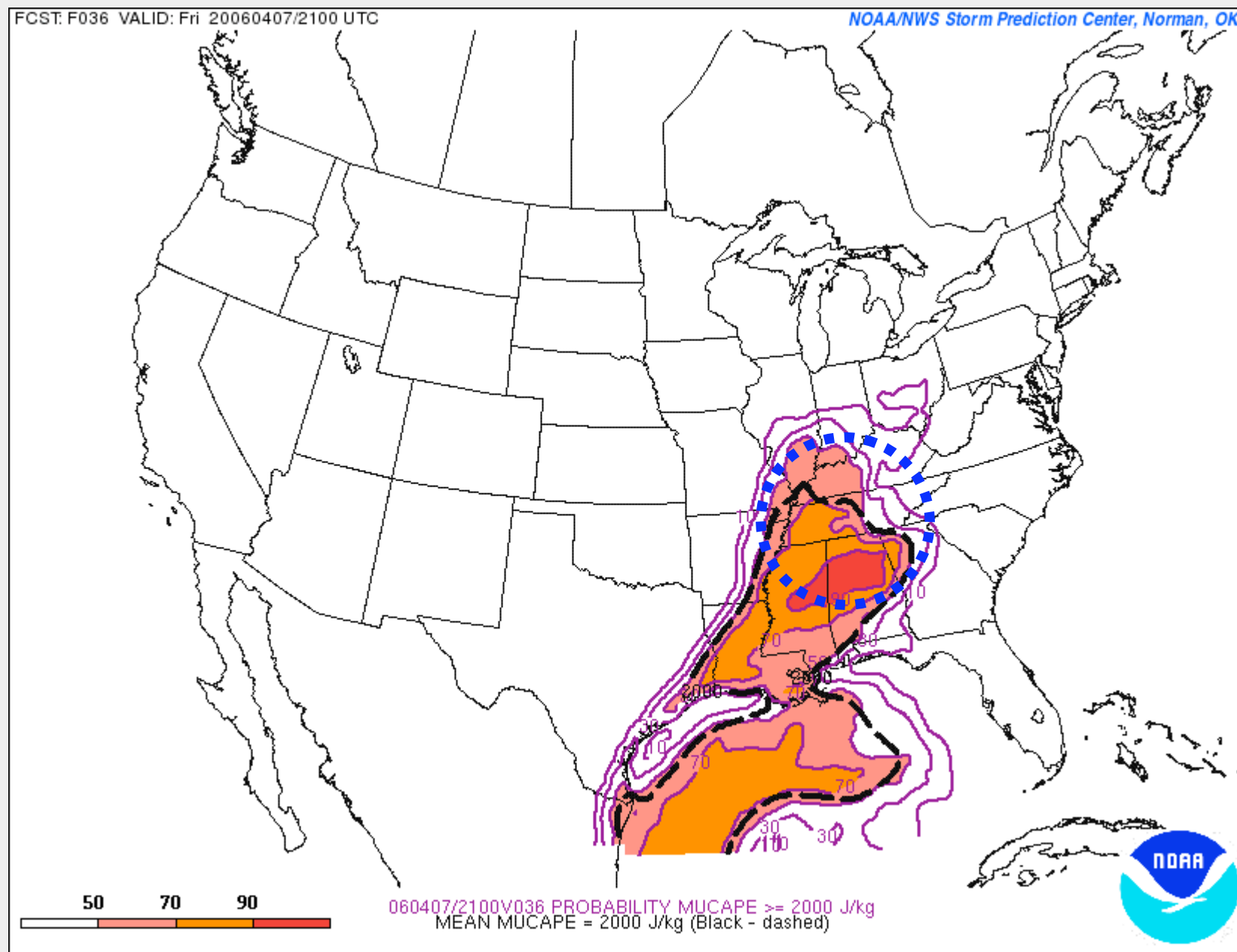
SREF 850 mb Mean Height, Wind, Temp



SREF Precipitable Water (Spaghetti = 1")



SREF Pr[MUCAPE \geq 2000 J/kg] & Mean MUCAPE=2000 (dash)

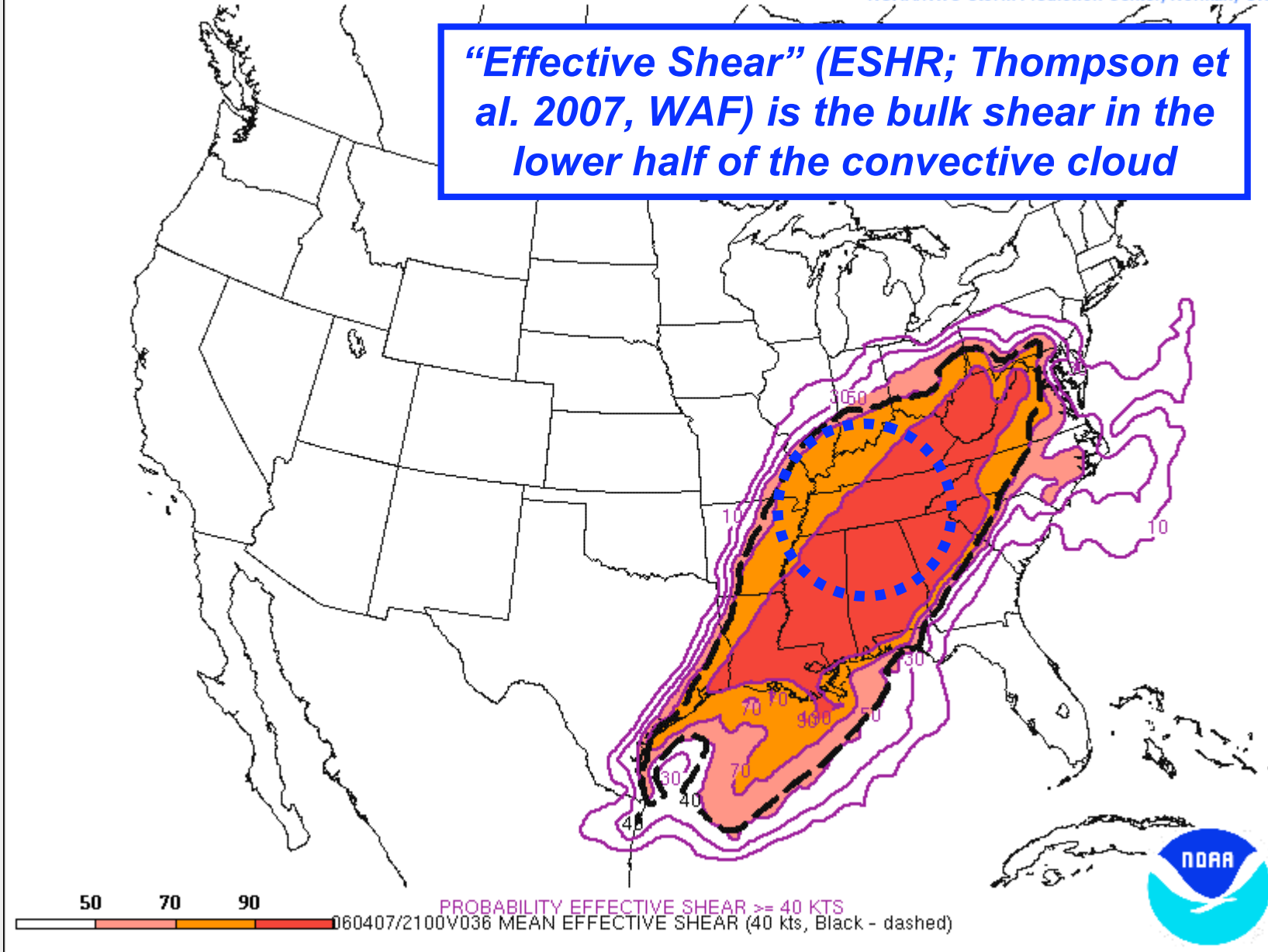


SREF Pr[ESHR \geq 40 kts] & Mean ESHR=40 kts (dash)

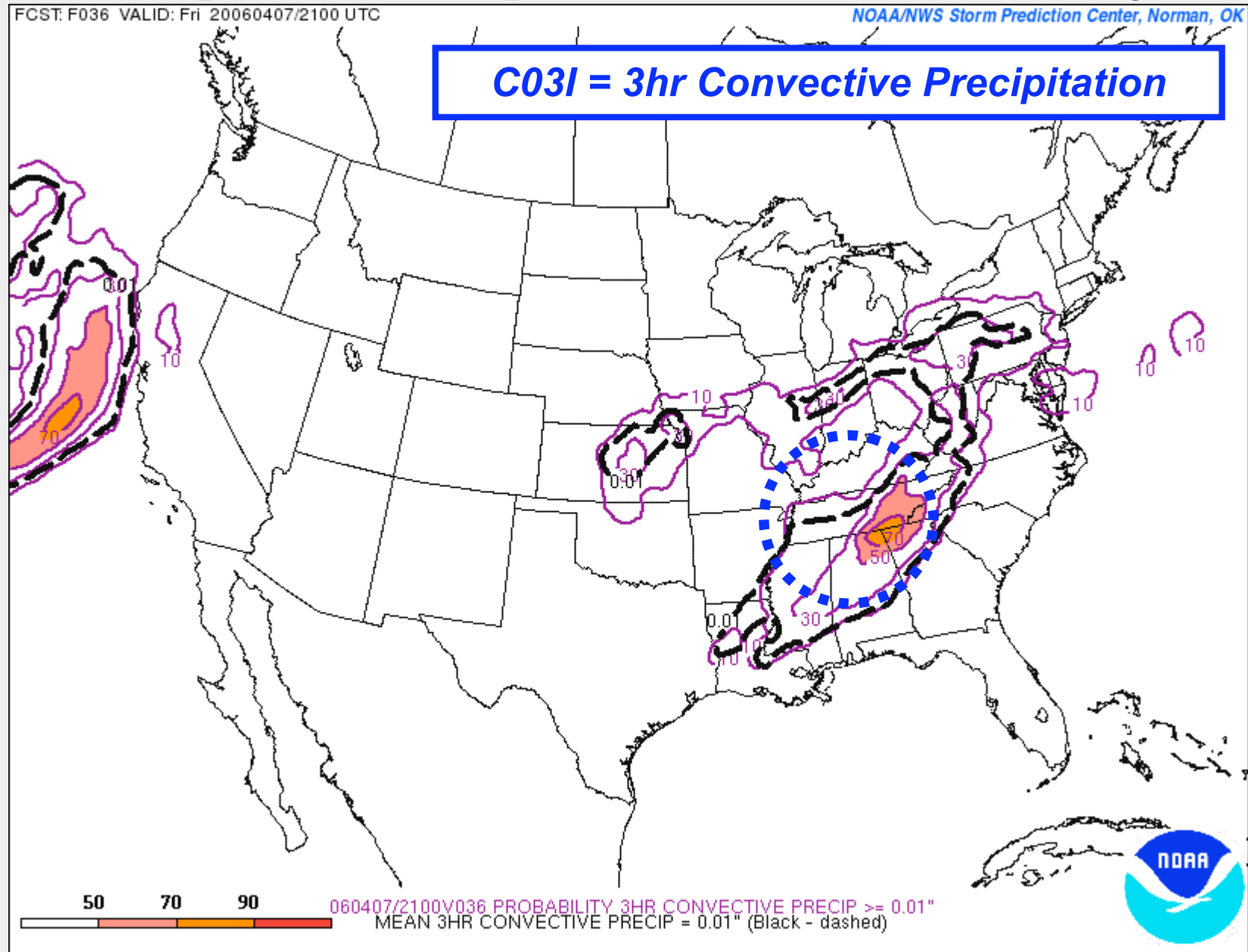
FCST: F036 VALID: Fri 20060407/2100 UTC

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“Effective Shear” (ESHR; Thompson et al. 2007, WAF) is the bulk shear in the lower half of the convective cloud



SREF Pr[C03I \geq .01"] and Mean C03I = .01" (dash)

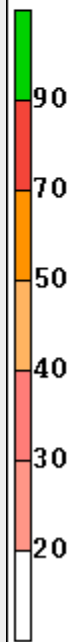


SREF Combined or Joint Probability

FCST: F036 VALID: Fri 20060407/2100 UTC

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*Probability of convection in high
CAPE, high shear environment
(favorable for supercells)*



**Pr [MUCAPE \geq 2000 J/kg] X
Pr [ESHR \geq 40 kts] X
Pr [C03I \geq 0.01"]**

060407/2100V036 PROB[C03I] \geq 0.01" X PROB[MUCAPE] \geq 2000 J/KG X PROB[EFFSM9MULQUOM1SHR] \geq 40 K

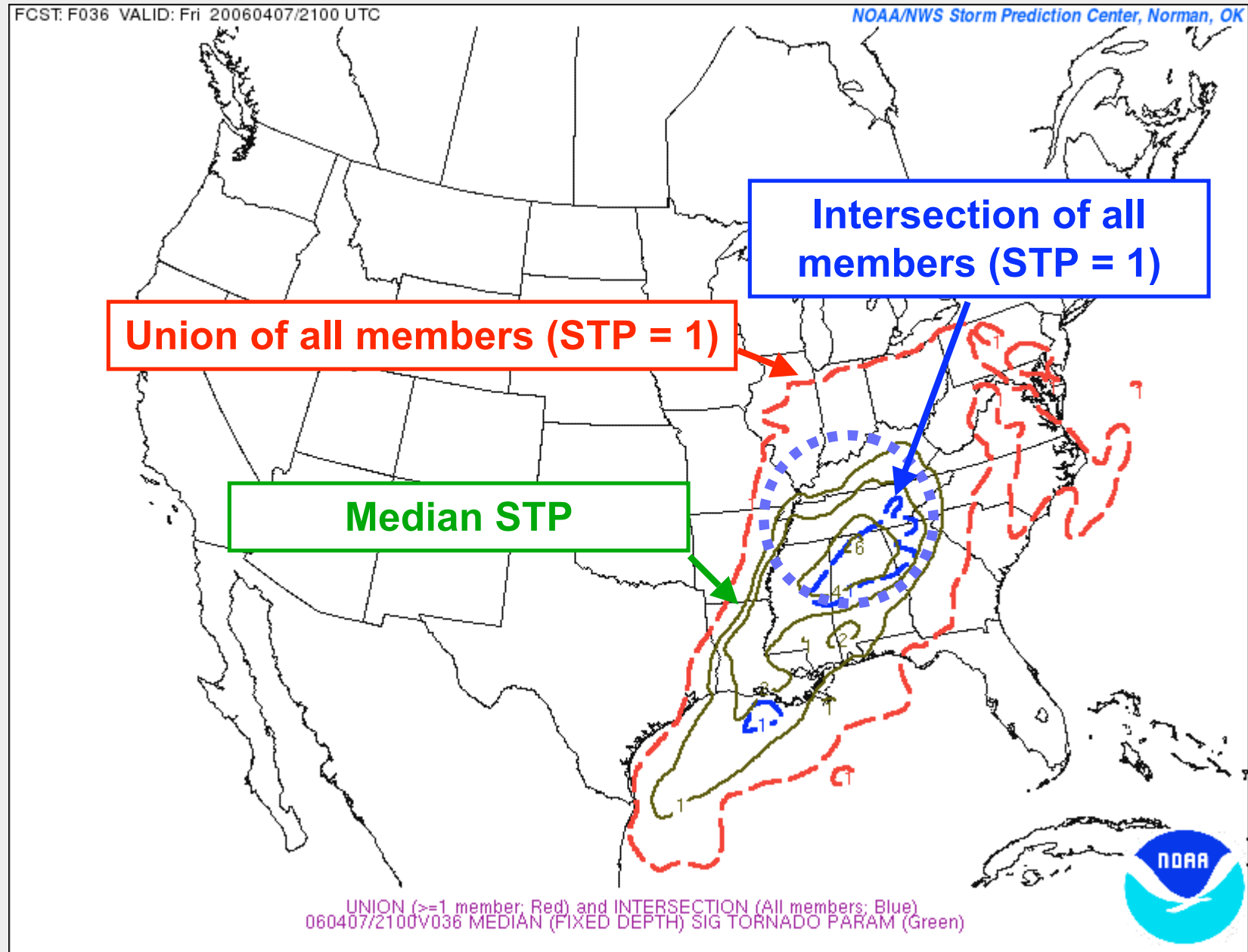


Diagnostics and Analysis

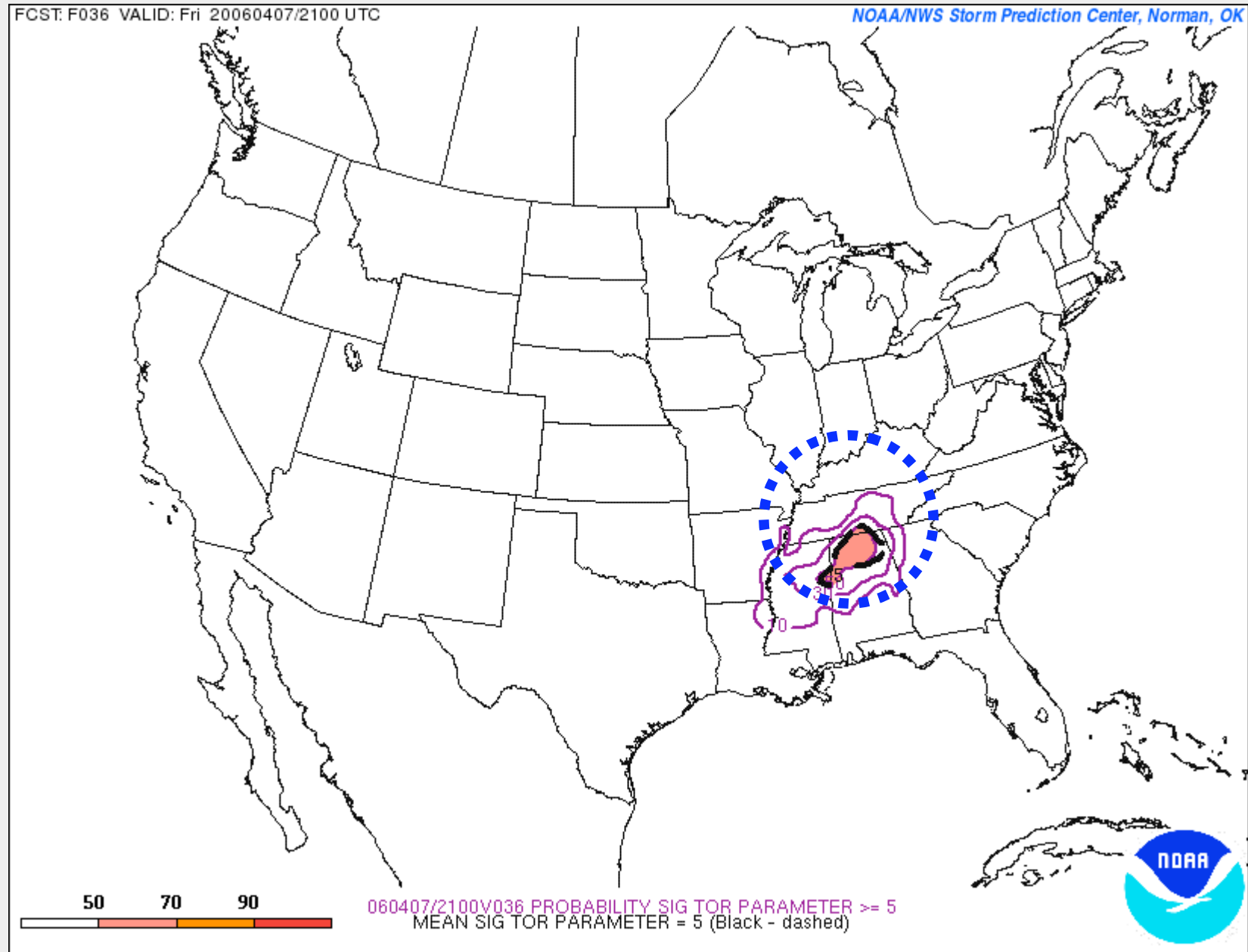
- Example: *Significant Tornado Parameter (STP)*
 - A parameter designed to help forecasters identify supercell environments capable of producing significant (\geq F2) tornadoes (Thompson et al. 2003)
- $STP = \mathcal{F}(MLCAPE, MLLCL, Helicity, Deep\ shear)^*$
 - $STP \geq \sim 1$ indicative of environments that may support strong or violent tornadoes (given that convection occurs)

** An updated version (not shown) includes CIN and effective depth*

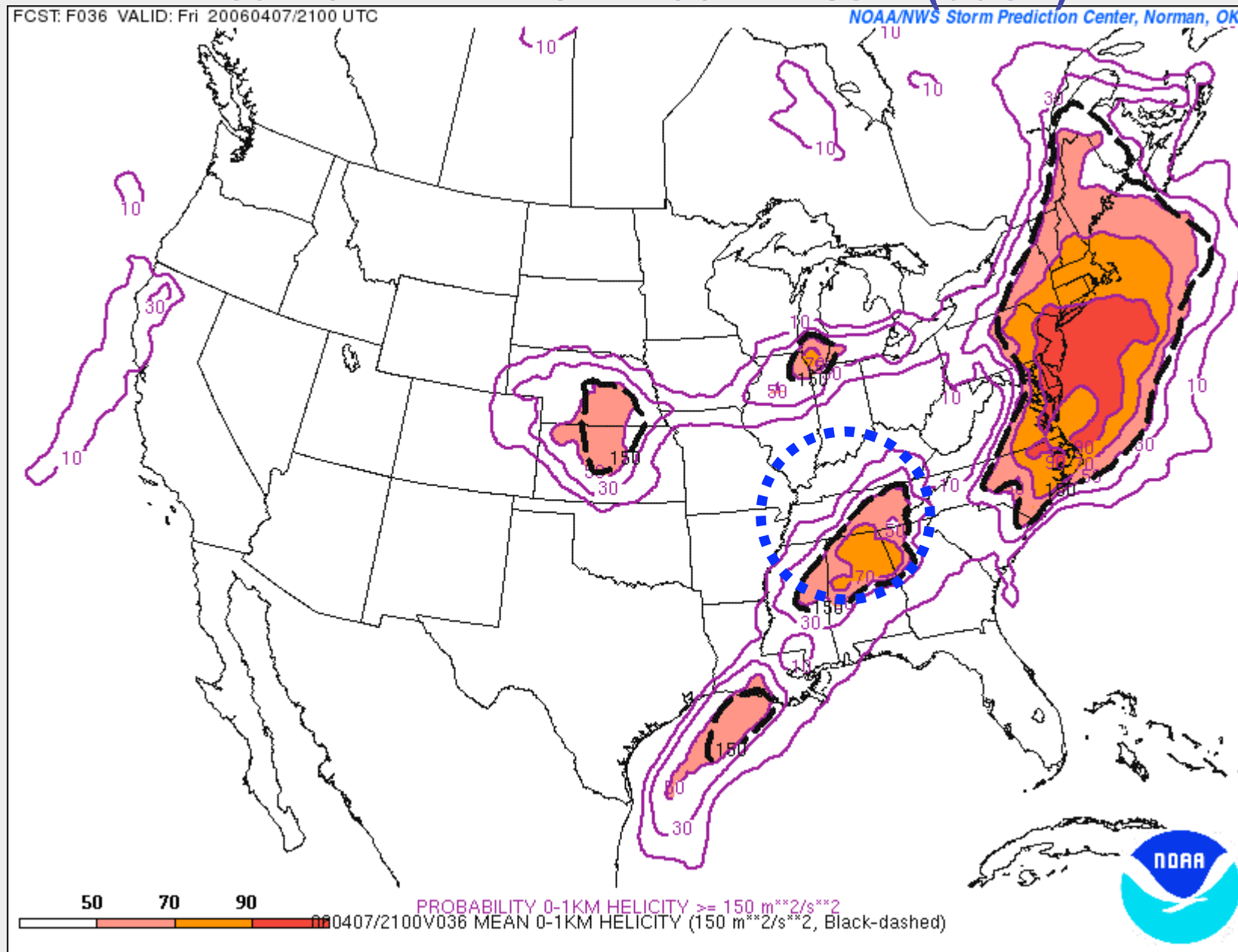
SREF Median STP, Union (red), Intersection (blue)



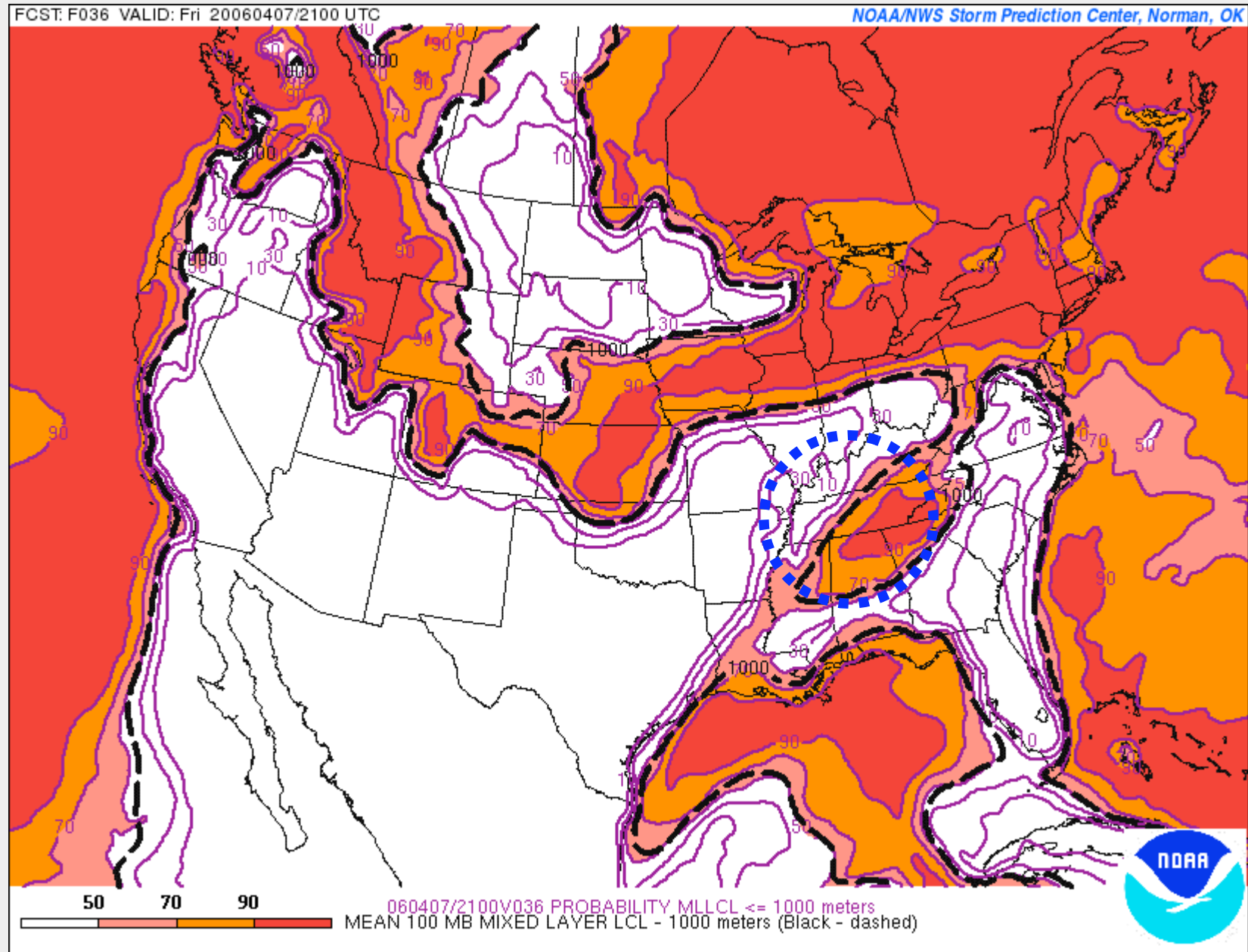
SREF Pr[STP ≥ 5] and Mean STP = 5 (dash)



SREF Pr[0-1KM HLCY $\geq 150 \text{ m}^2/\text{s}^2$] & Mean 0-1KM HLCY=150 m^2/s^2 (dash)



SREF Pr[MLLCL \leq 1000m] & Mean MLLCL = 1000 m (dash)



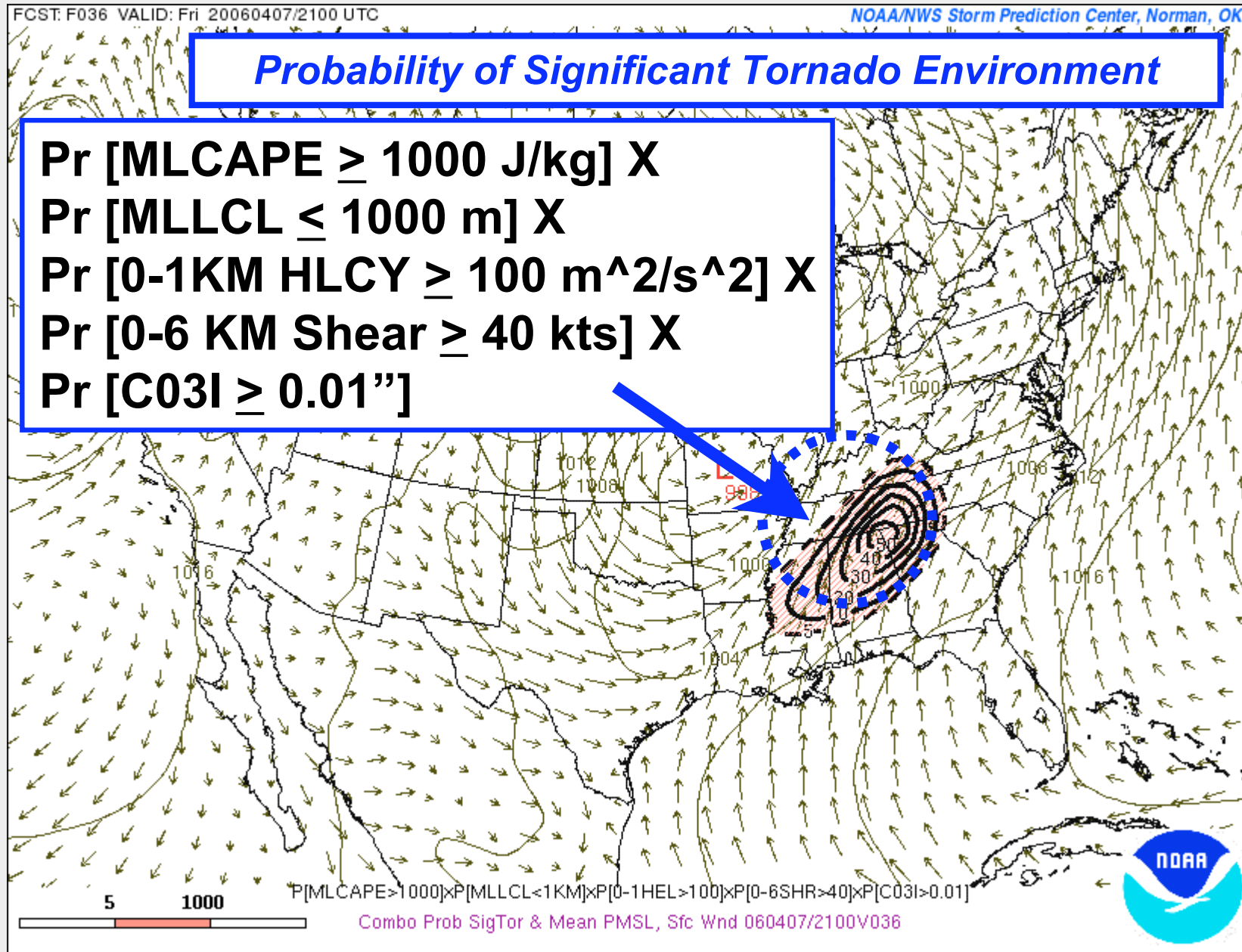
SREF Combined or Joint Probability: STP Ingredients

FCST: F036 VALID: Fri 20060407/2100 UTC

NOAA/NWS Storm Prediction Center, Norman, OK

Probability of Significant Tornado Environment

Pr [MLCAPE \geq 1000 J/kg] X
Pr [MLLCL \leq 1000 m] X
Pr [0-1KM HLCY \geq 100 m²/s²] X
Pr [0-6 KM Shear \geq 40 kts] X
Pr [C03I \geq 0.01"]

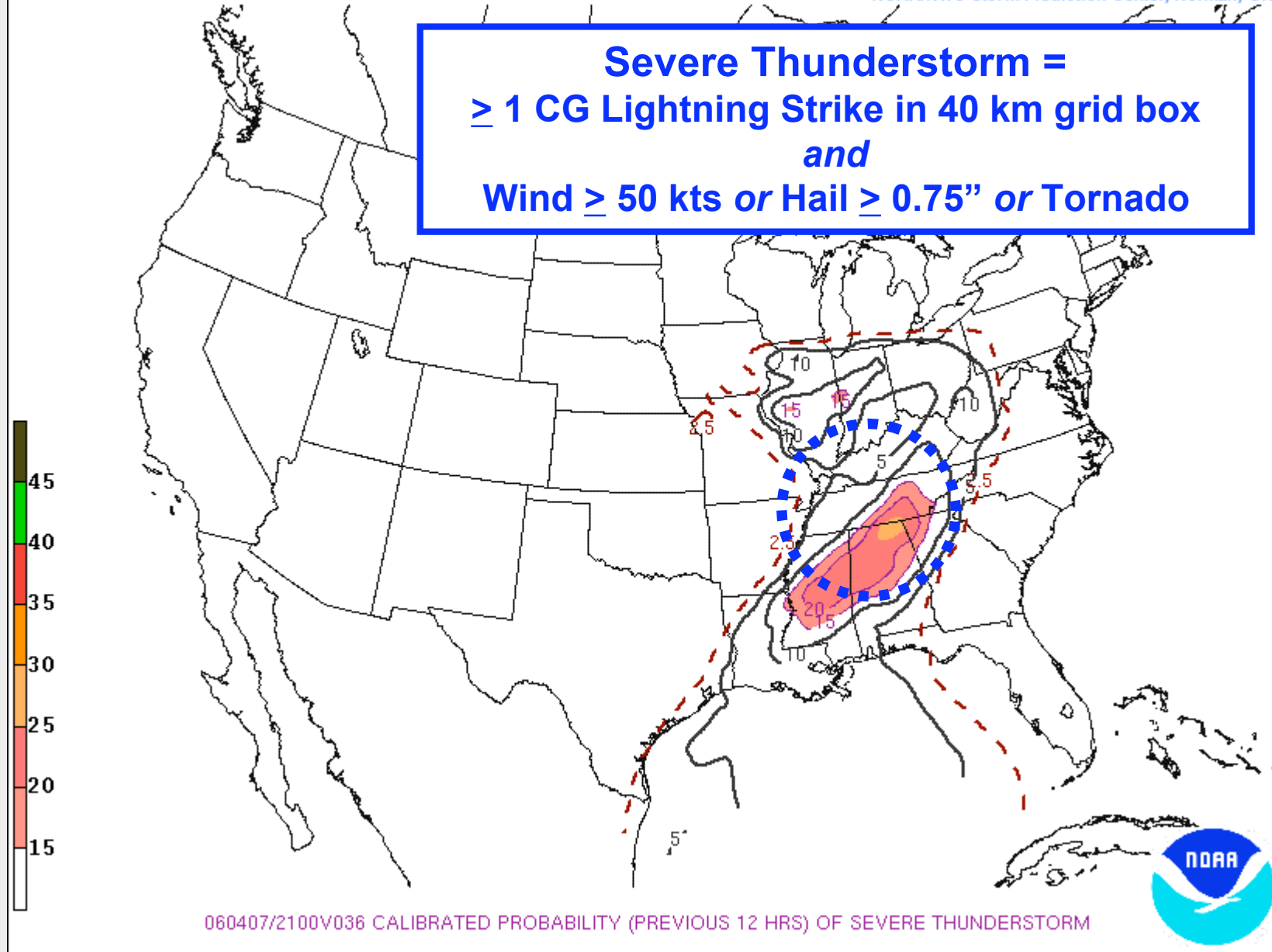


SREF 12h Calibrated Probability of Severe Thunderstorms

FCST: F036 VALID: Fri 20060407/2100 UTC

NOAA/NWS Storm Prediction Center, Norman, OK

Severe Thunderstorm =
 ≥ 1 CG Lightning Strike in 40 km grid box
and
Wind ≥ 50 kts or Hail ≥ 0.75 " or Tornado



SREF Probability of STP Ingredients: Time Trends

48 hr SREF Forecast Valid 21 UTC 7 April 2006

Prob (MLCAPE $\geq 1000 \text{ Jkg}^{-1}$)

X

Prob (6 km Shear $\geq 40 \text{ kt}$)

X

Prob (0-1 km SRH $\geq 100 \text{ m}^2\text{s}^{-2}$)

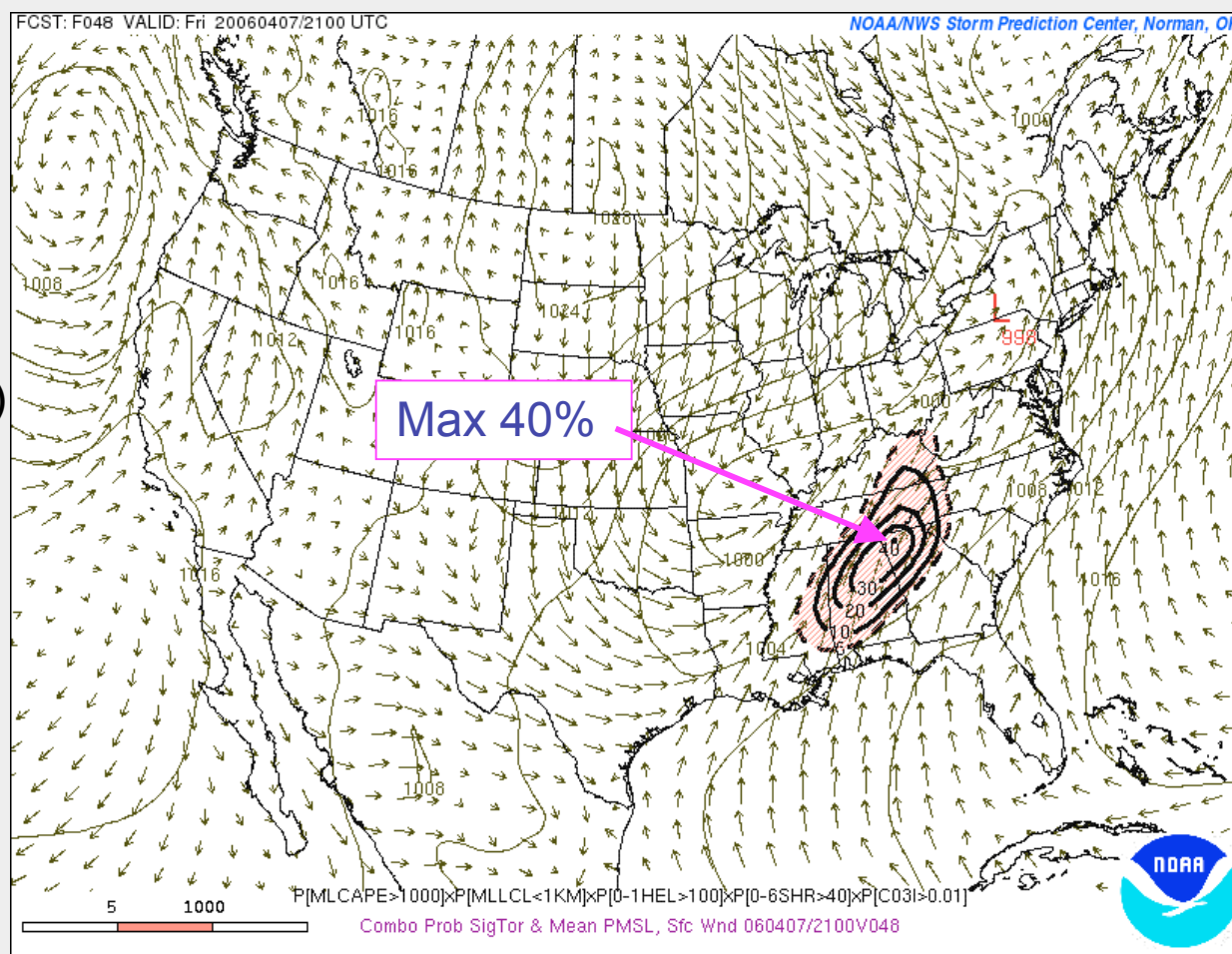
X

Prob (MLLCL $\leq 1000 \text{ m}$)

X

Prob (3h conv. Pcpn $\geq 0.01 \text{ in}$)

Shaded Area Prob $\geq 5\%$



SREF Probability of STP Ingredients: Time Trends

36 hr SREF Forecast Valid 21 UTC 7 April 2006

Prob (MLCAPE $\geq 1000 \text{ Jkg}^{-1}$)

X

Prob (6 km Shear $\geq 40 \text{ kt}$)

X

Prob (0-1 km SRH $\geq 100 \text{ m}^2\text{s}^{-2}$)

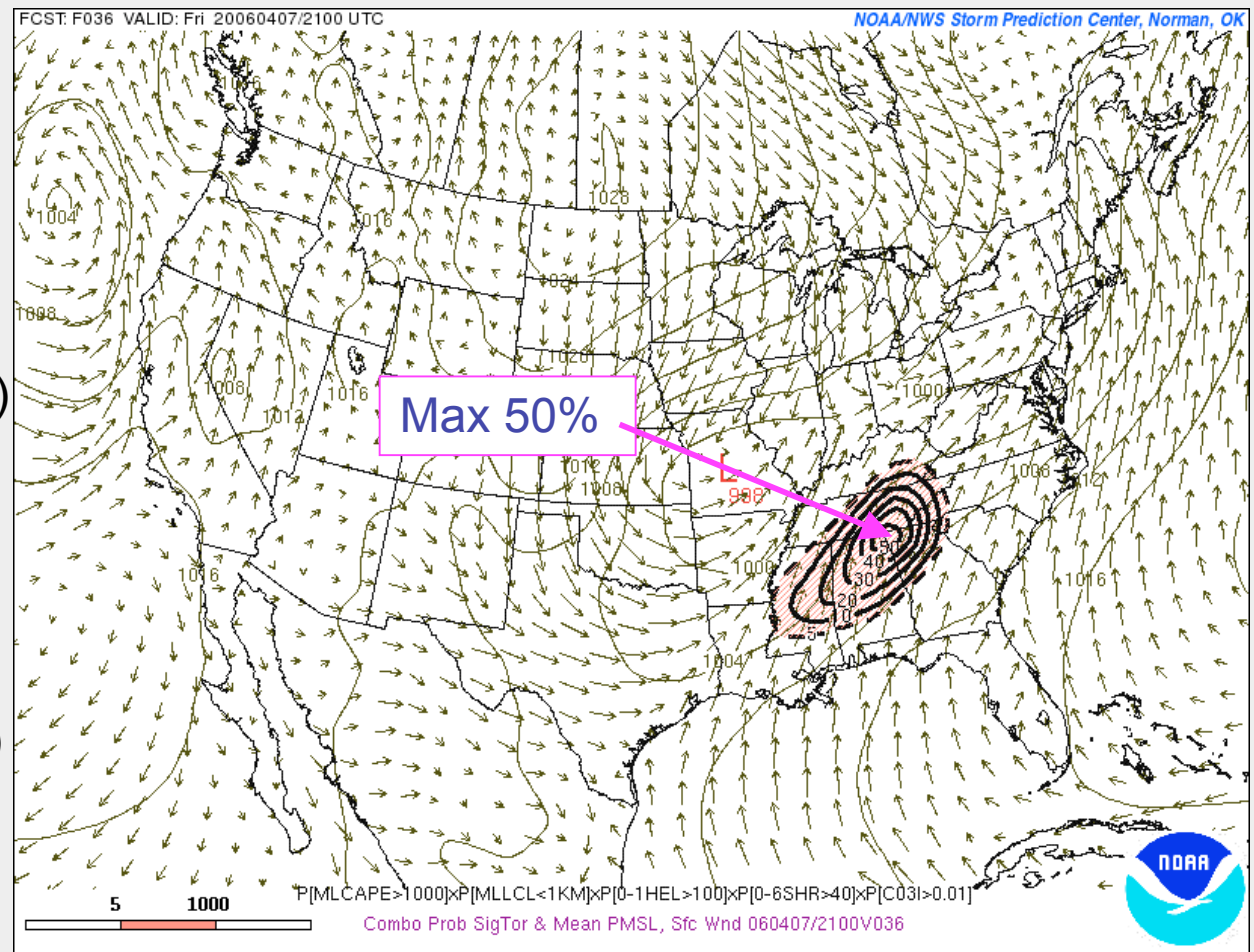
X

Prob (MLLCL $\leq 1000 \text{ m}$)

X

Prob (3h conv. Pcpn $\geq 0.01 \text{ in}$)

Shaded Area Prob $\geq 5\%$



SREF Probability of STP Ingredients: Time Trends

24 hr SREF Forecast Valid 21 UTC 7 April 2006

Prob (MLCAPE $\geq 1000 \text{ Jkg}^{-1}$)

X

Prob (6 km Shear $\geq 40 \text{ kt}$)

X

Prob (0-1 km SRH $\geq 100 \text{ m}^2\text{s}^{-2}$)

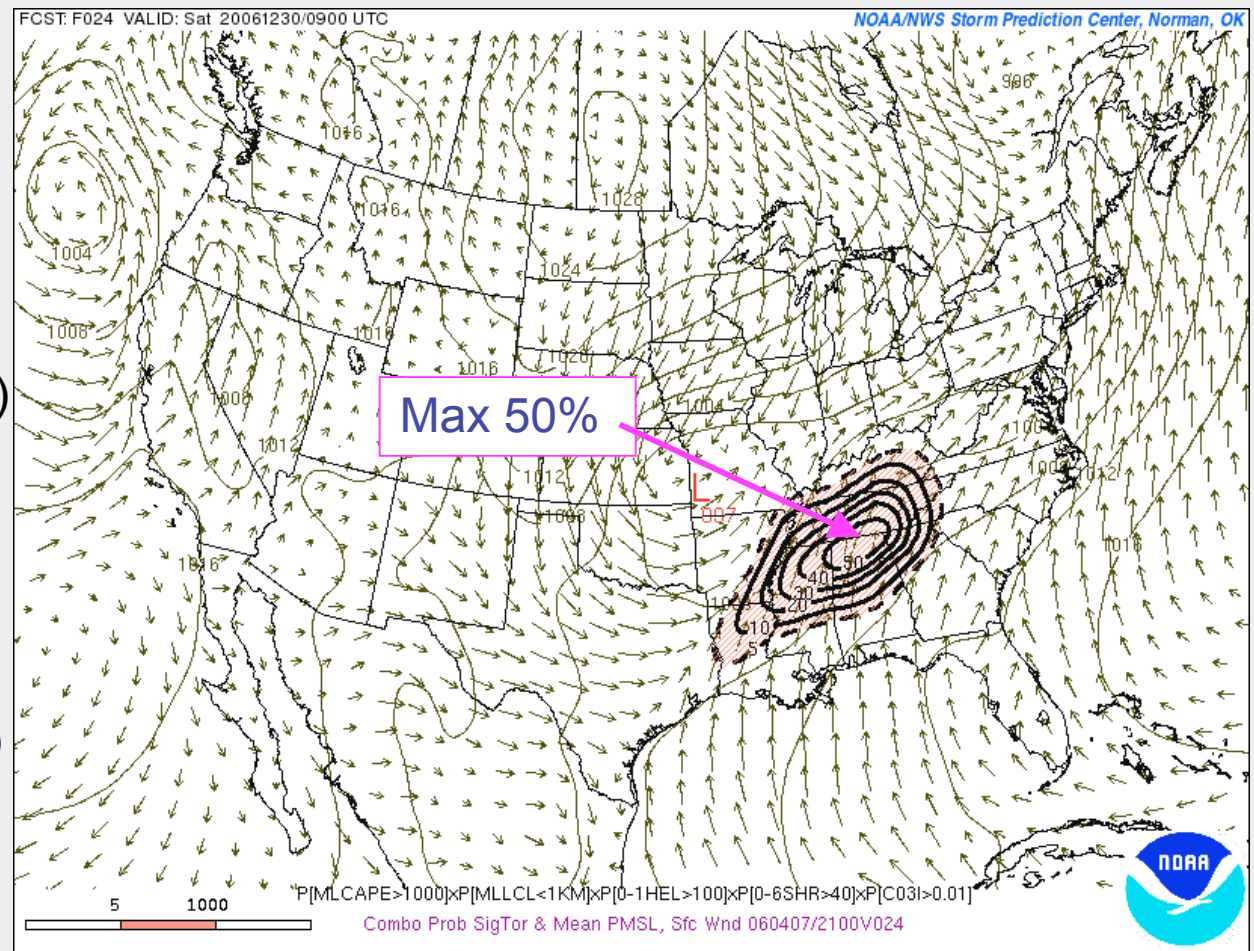
X

Prob (MLLCL $\leq 1000 \text{ m}$)

X

Prob (3h conv. Pcpn $\geq 0.01 \text{ in}$)

Shaded Area Prob $\geq 5\%$



SREF Probability of STP Ingredients: Time Trends

12 hr SREF Forecast Valid 21 UTC 7 April 2006

Prob (MLCAPE $\geq 1000 \text{ Jkg}^{-1}$)

X

Prob (6 km Shear $\geq 40 \text{ kt}$)

X

Prob (0-1 km SRH $\geq 100 \text{ m}^2\text{s}^{-2}$)

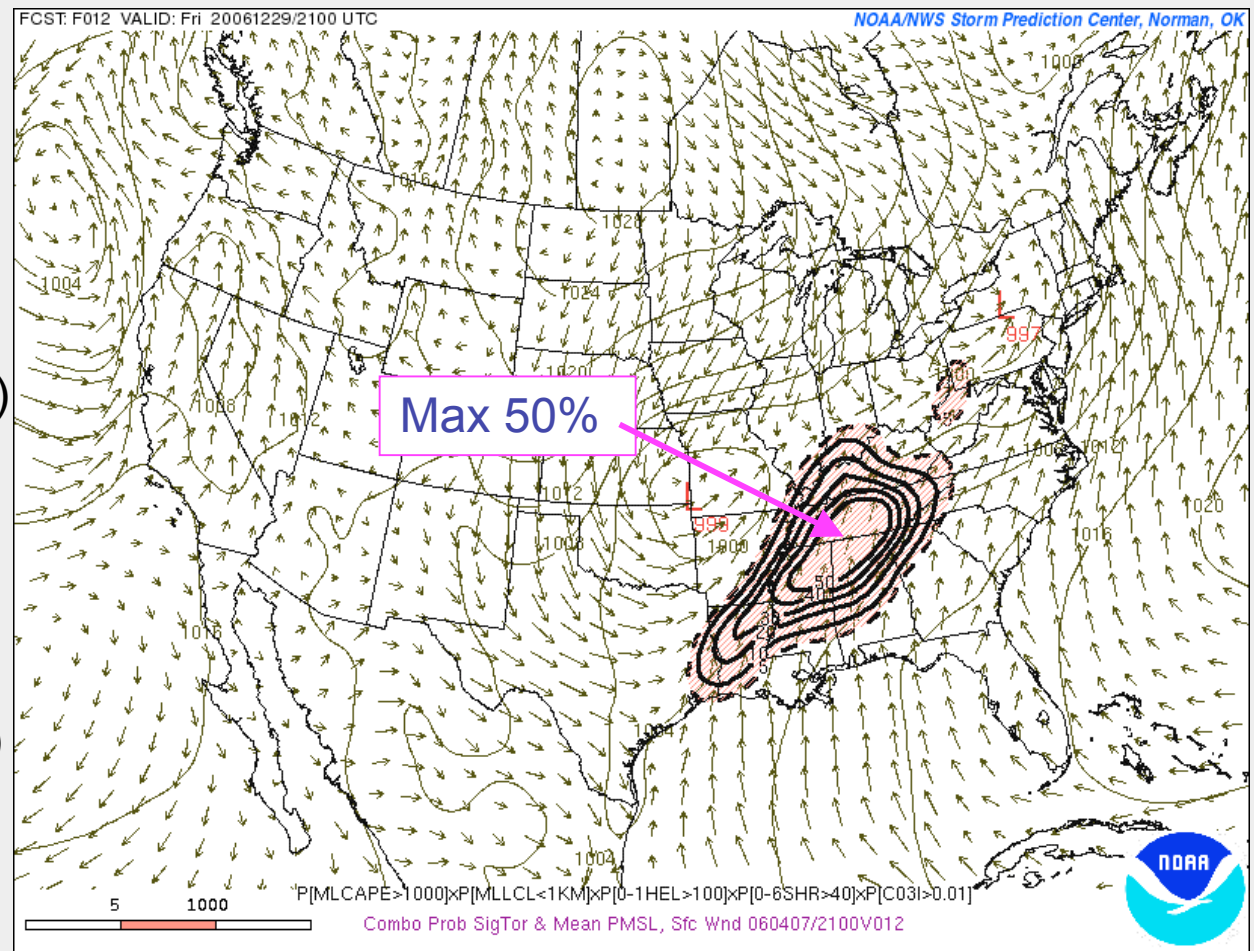
X

Prob (MLLCL $\leq 1000 \text{ m}$)

X

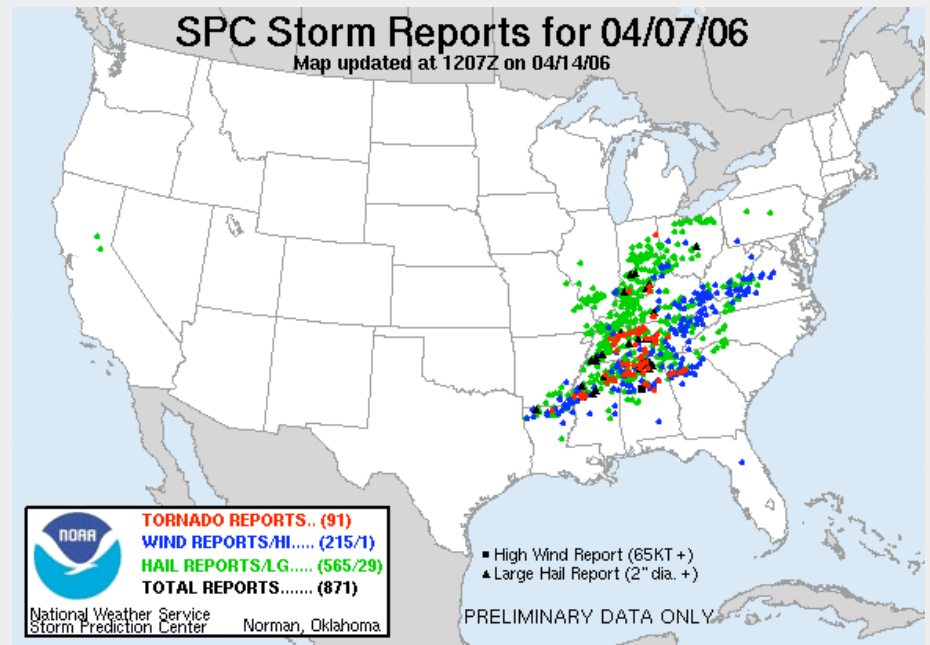
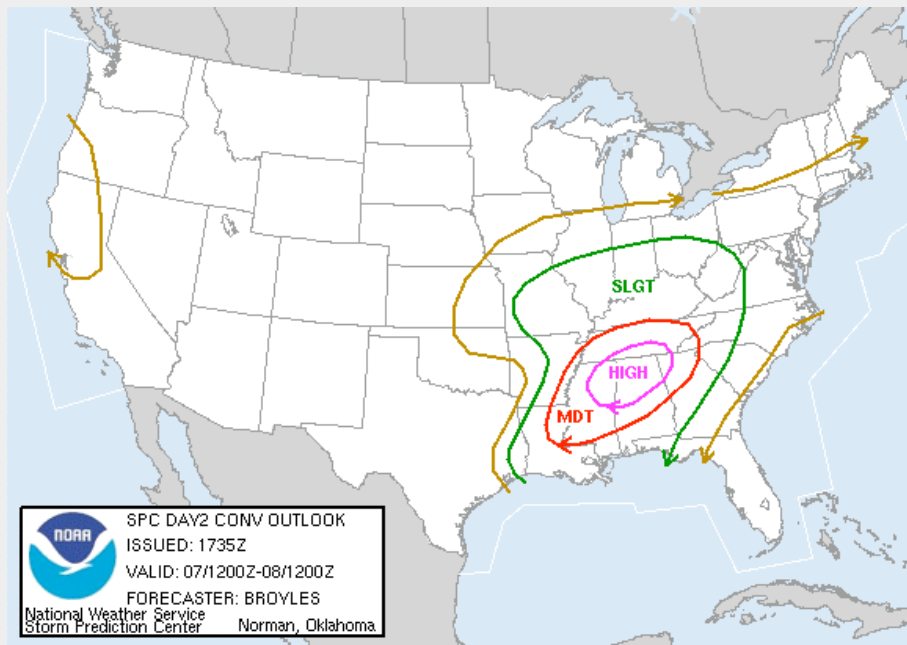
Prob (3h conv. Pcpn $\geq 0.01 \text{ in}$)

Shaded Area Prob $\geq 5\%$



Severe Event of April 7, 2006

- **First ever** Day 2 outlook High Risk issued by SPC
- More than 800 total severe reports
 - 3 killer tornadoes and 10 deaths
- SREF severe weather fields aided forecaster confidence

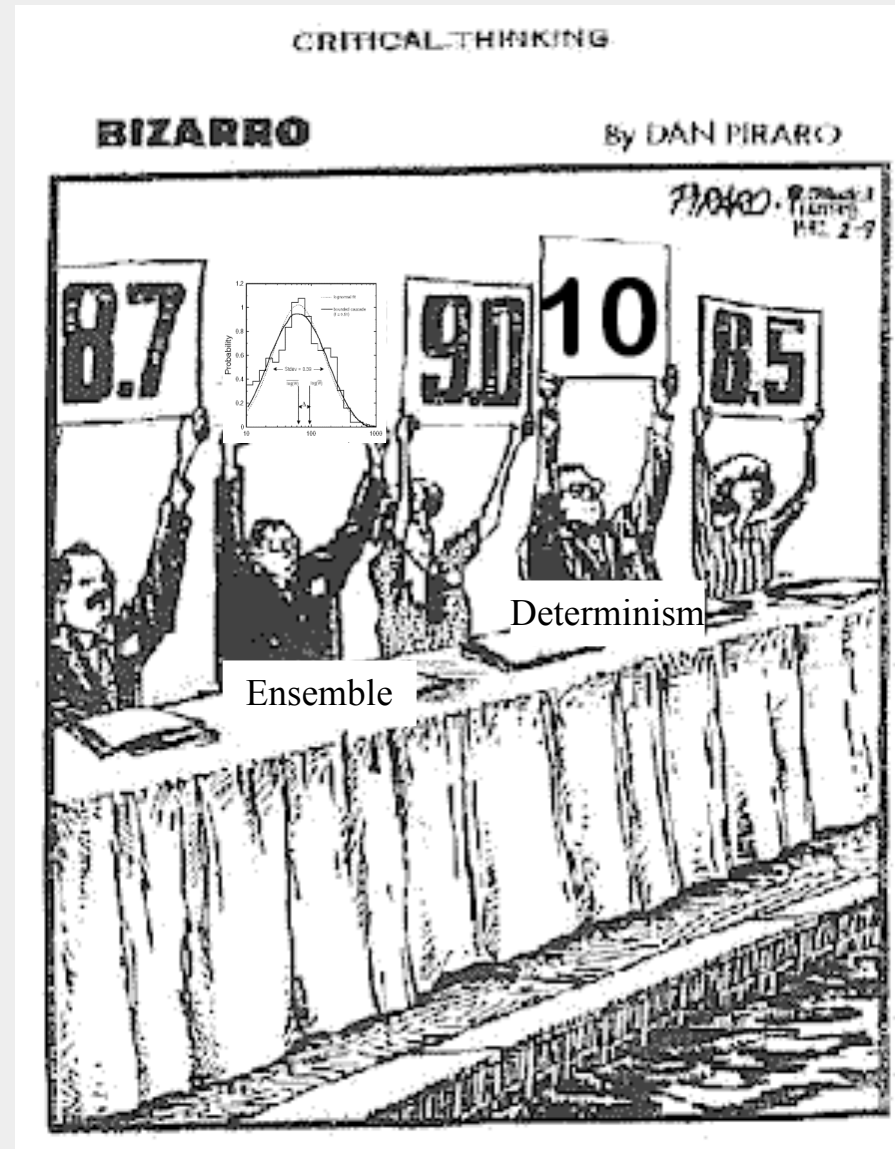


Outline

- Introduction
- Applications in Severe Weather Forecasting
 - Fire Weather
 - Winter Weather
 - Severe Convective Weather
- Summary



What is the perfect forecast?



Ensemble Applications in Severe Forecasting

- **Ensemble approach to forecasting similar to the deterministic approach**
 - Ingredients based inputs
 - Diagnostic and parameter evaluation
 - Tend to view diagnostics in probability space
- **Ensembles contribute appropriate levels of confidence to the forecast process**
- **Calibration of ensemble output can remove systematic biases and improve the spread**
- **Ensemble techniques scale to the problem of interest (weeks, days, or hours)**

Looking Ahead: Storm-Scale Ensembles

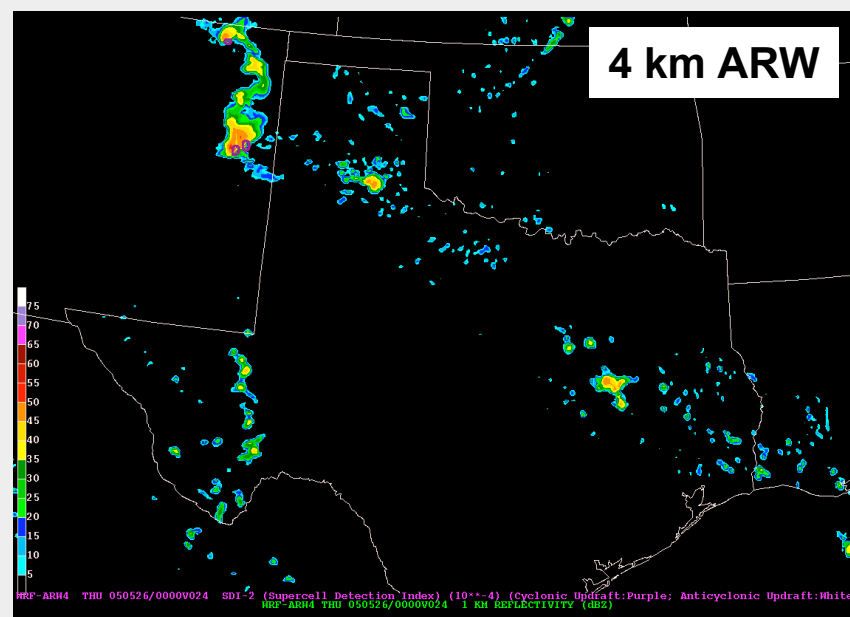
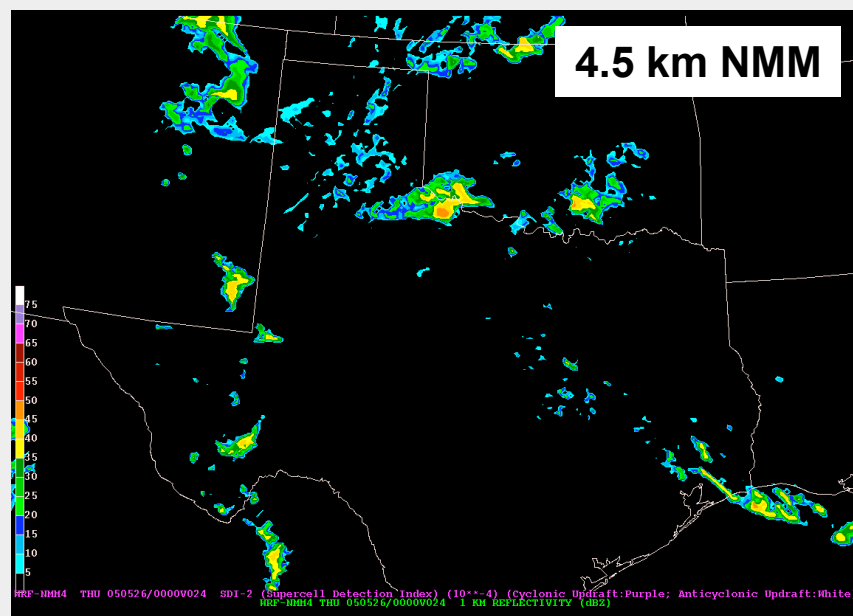
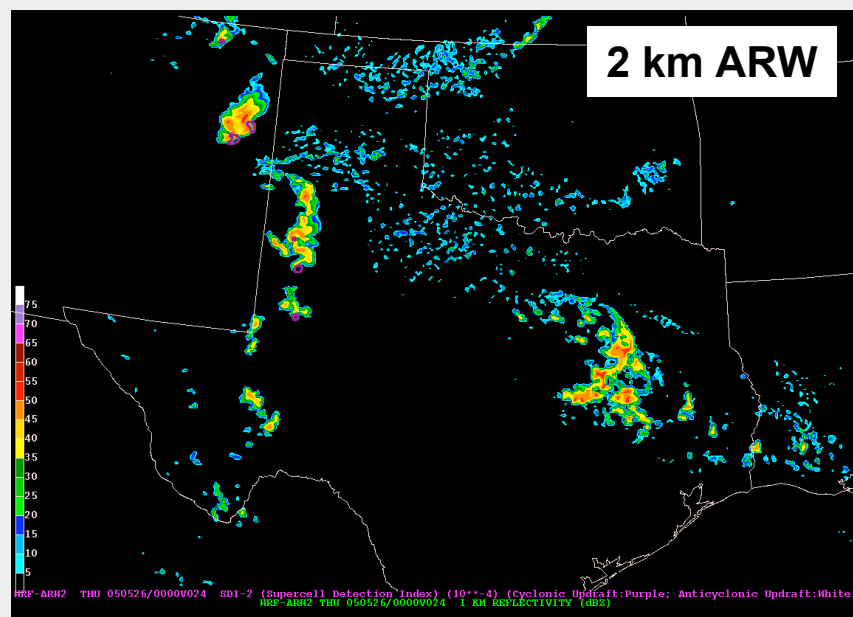
- Ensemble techniques scale to the problem of interest (weeks, days, or hours)
- Example from SPC/NSSL 2005 Spring Program:
 - 3 very high resolution WRF models allowed for the creation of a “Poor person’s ensemble”
 - WRF-ARW2 (2 km grid space; OU/CAPS)
 - WRF-ARW4 (4 km grid space; NCAR)
 - WRF-NMM (4.5 km grid space; NCEP/EMC)
 - Explicit, convection allowing forecasts
 - Interested in resolved storm-scale structures
 - Initiation, Mode, Evolution, Decay

WRF 2 to 4.5 km

Forecasts

Valid: F024

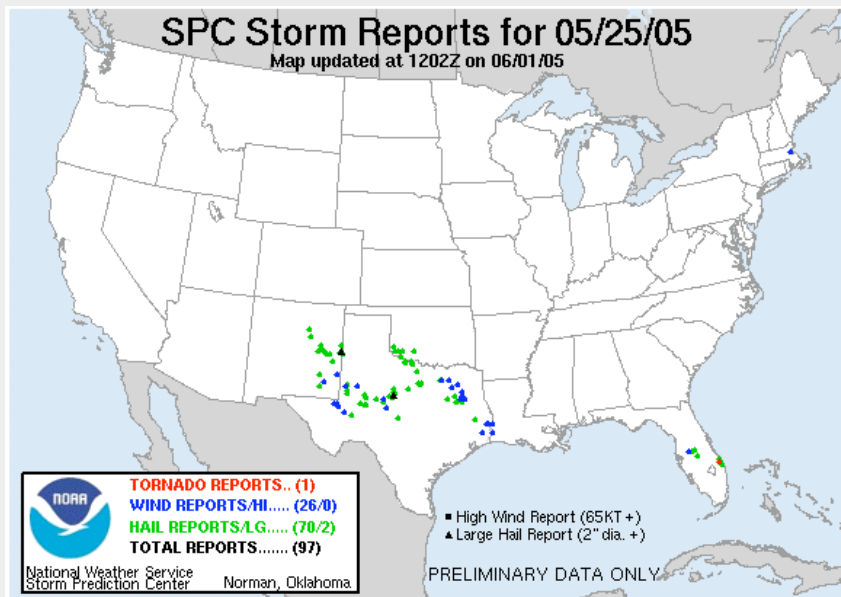
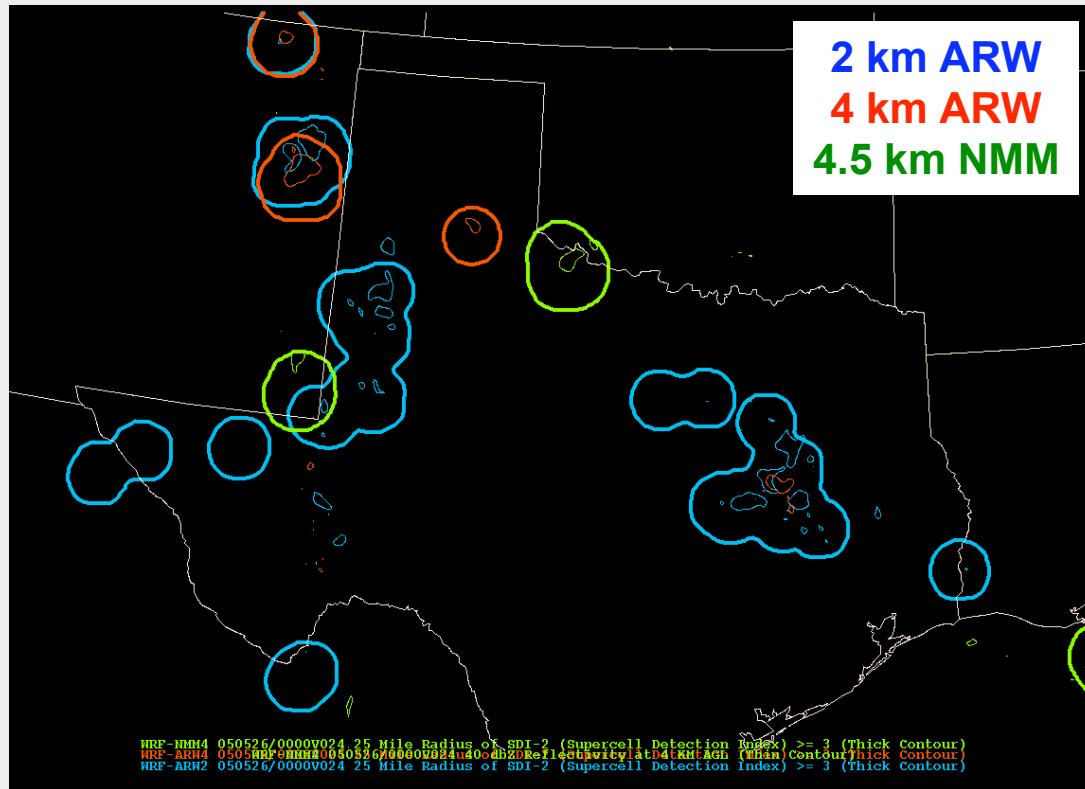
26 May 2005



WRF 2 to 4.5 km Forecasts

Valid: F024
26 May 2005

“Spaghetti” of automated
supercell detection:
*circles indicate a supercell
identified within 25 miles*



All three WRF models
contribute information to
the supercell forecast

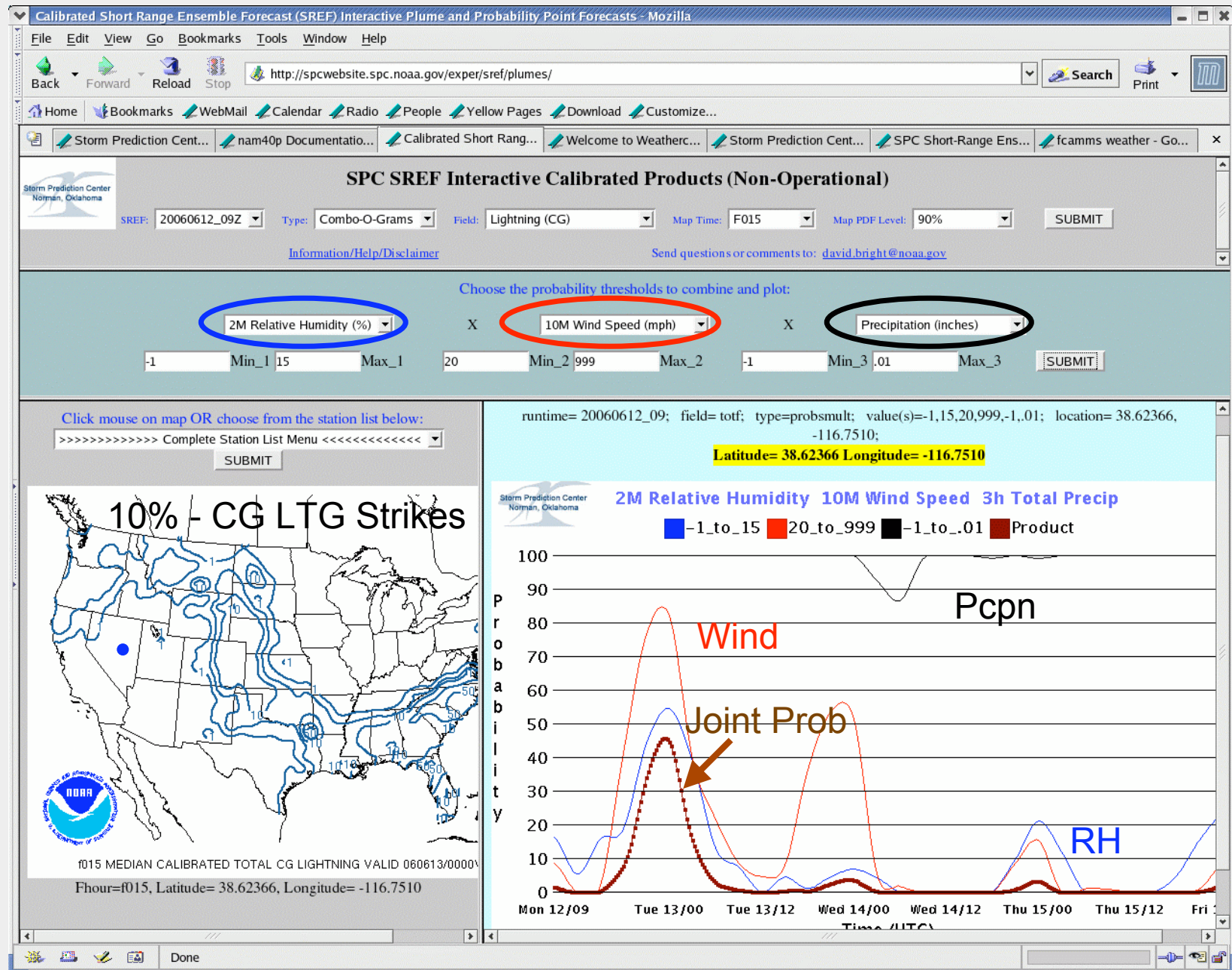
Storm-Scale Ensemble

NOAA Hazardous Weather Testbed (HWT)

- 2007 Spring Experiment will continue 2005 work
 - ~15 April 2007 through ~15 June 2007
 - 2008 and 2009 will incorporate WRF-NMM and various upgrades
- Collaboration between SPC and NSSL
 - OU/CAPS (NWC)
 - NCEP partners: AWC, EMC, HPC
 - WFO Norman
- 10 members, 4 km explicit convection allowing mixed physics WRFs (eastern 2/3 CONUS)
 - 2 km high-resolution deterministic WRF to accompany ensemble
- Emphasis on revolved, high-impact hazardous weather (e.g., supercells, mode, coverage, QPF)
 - Prototype for future NCEP regional SREF system



Combined Prob-o-Grams (SREF – Cntrl NV)



SPC SREF Products on WEB

<http://www.spc.noaa.gov/exper/sref/>

The screenshot shows the NOAA Storm Prediction Center's Short Range Ensemble Forecast (SREF) web page. The browser window title is "Storm Prediction Center - Short Range Ensemble Forecast (SREF) Pages - SeaMonkey". The address bar shows the URL <http://www.spc.noaa.gov/exper/sref/>. The page features the NOAA logo and the text "NOAA's National Weather Service Storm Prediction Center". A navigation bar includes links for "Site Map", "News", "Organization", and a search bar. A left sidebar contains various links categorized under "Overview", "Weather Information", "Research", "Education & Outreach", and "Misc.". The main content area is titled "SPC Short Range Ensemble Forecast (SREF) Page" and includes a prompt to "Click on desired model run (format: YYYYMMDDHHZ)". Below this is a map of the United States showing weather patterns with pressure systems (e.g., 542, 590 H) and precipitation forecasts. A large orange box with a black border is overlaid on the map, containing the text "Questions/Comments... david.bright@noaa.gov". At the bottom of the page, a note states: "Note: Those users interested in quickly accessing the most recent SREF model run can save the following link to their web browser: [Latest SREF Run](#)."

Questions/Comments...
david.bright@noaa.gov